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GATES BROOK STORMWATER STUDY

(WACHUSETT RESERVOIR)

1990 THROUGH 1991

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Prepared by

Department of Environmental Protection
Office of Watershed Management
North Grafton

and

Metropolitan District Commission
Division of Watershed Management
Environmental Quality Section
Boston

MAY 1994

COMMONWEALTH OF MASSACHUSETTS

EXECUTIVE OFFICE OF ENVIRONMENTAL AFFAIRS
Trudy Coxe, Secretary

DEPARTMENT OF ENVIRONMENTAL PROTECTION
Thomas Powers, Acting Commissioner

OFFICE OF WATERSHED MANAGEMENT
Andrew Gottlieb, Director

METROPOLITAN DISTRICT COMMISSION
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FOREWORD

METROPOLITAN DISTRICT COMMISSION (MDC)

The Metropolitan District Commission's Division of Watershed Management (DWM) was established by the Massachusetts Legislature in 1984 and officially began operations on July 1, 1985. The legislative mission of the organization is to"...construct, maintain and operate a system of watershed, reservoirs, water rights in sources of supply in order to provide a sufficient supply of pure water to the Massachusetts Water Resources Authority." The Division must conserve and protect these resources in order to ensure the purity of the drinking water supply.

As provided in the enabling legislation, the Division of Watershed Management is responsible for monitoring the streams and reservoirs of the system and for conducting sanitary surveys of the watersheds. The DWM's Environmental Quality Section performs theses tasks in order to ensure that Class A Water Quality Standards are met. MDC-DWM has responsibility for monitoring upstream of the distribution intakes, considered to be the Cosgrove Aqueduct at Wachusett Reservoir, the Winsor Dam at Quabbin Reservoir, and Shaft 4 at Sudbury Reservoir. The Massachusetts Water Resources Authority is responsible for monitoring the distribution system.

MASSACHUSETTS DIVISION OF WATER POLLUTION CONTROL (DWPC) AND OFFICE OF WATERSHED MANAGEMENT (OWM)

The Massachusetts Division of Water Pollution Control was established by the Massachusetts Clean Water Act, Chapter 21 of the General Laws as amended by Chapter 685 of the Acts of 1966. Included in the duties and responsibilities of the Division is the periodic examination of the water quality of various coastal waters, rivers, streams, and ponds of the Commonwealth, as stated in Section 27, Paragraph 5 of the Acts. This section further directs the Division to publish the results of such examination, together with the standards of water quality established for the various waters. The Office of Watershed Management (OWM) in North Grafton, MA (formerly part of DWPC Technical Services Section), has among its responsibilities, the execution of this directive. This report is published under the authority of the Acts, and is among a continuing series of reports issued by the DWPC and OWM presenting water quality data and analyses, water quality management plans, baseline and intensive limnological studies and special studies.

DISCLAIMER

Reference to trade names, commercial products, manufacturers, or distributors in this report constitutes neither endorsement nor recommendation by the Massachusetts DEP/Division of Water Pollution Control or DEP/Office of Watershed Management.

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1.0 Introduction

1.1 MDC/DWM Goals and Objectives

The Division of Watershed Management (DWM) of the Metropolitan District Commission (MDC) operates and maintains a system of watersheds and reservoirs that provide drinking water for approximately 2.5 million people in 46 communities throughout the Commonwealth of Massachusetts. The watershed system, depicted in **Figure 2-1**, includes in excess of 303,000 acres of land and water in the Quabbin, Wachusett and Ware River watersheds in central Massachusetts. This system comprises the largest water supply in New England and one of the largest unfiltered sources of supply in the United States.

Protection of these surface water supply sources is the primary mission of the DWM. The reservoirs and tributaries within this system are routinely sampled by the Environmental Quality section of the DWM. Analysis of water quality data indicates that stormwater contributes significant pollutant loads within some subwatersheds within the system. The objective of this project is to conduct a stormwater sampling program to characterize stormwater and enable more accurate assessment of stormwater impacts on water quality within the water supply system. Such characterization is a necessary first step toward the development of a comprehensive stormwater management strategy for the improvement of water quality within the watershed system.

1.2 DEP/OWM Goals and Objectives

The Massachusetts Department of Environmental Protection (DEP) administers the state's environmental regulatory programs for the protection of air, water, and land resources.

In 1989, the DEP Division of Water Pollution Control (DWPC), currently named the Office of Watershed Management-OWM developed a long-term Nonpoint Source Management Plan (MA DEP, 1989) which identified Wachusett Reservoir as one of the highest priority waterbodies in the state. As part of this plan, DEP/OWM proposed to work with MDC to develop watershed management strategies related to nonpoint source problems and best management practices in the Wachusett watershed. The DEP agreed to provide water quality monitoring and assessment support to the MDC-DWM's watershed protection efforts. After discussing nonpoint sources of pollution in MDC watershed areas and outlining potential areas for joint studies that would meet NPS program objectives and provide sampling and analysis support to the MDC, the MDC and DEP chose the Gates Brook subwatershed for a cooperative stormwater sampling program. MDC and DEP/OWM met as the state's NonPoint Source Plan was developed to discuss nonpoint sources of pollution in MDC watershed areas, to outline potential areas in which to develop joint studies which would meet the NPS program objectives, and to provide sampling and analysis support to the MDC.

1.3 Program Purpose and Objectives

Routine sampling and water quality studies that have been conducted by the MDC-DWM have indicated that there is a substantial pollutant loading occurring in the Wachusett Reservoir due to stormwater flow from urbanized areas. The MDC and the DEP/OWM developed a pilot stormwater monitoring program in the Gates Brook subwatershed of Wachusett Reservoir to quantify stormwater pollutant loads to the reservoir, and to develop stormwater treatment and management criteria. The pollutant loading specific to the Gates Brook subwatershed was to be characterized and quantified so that the loading rates associated with the Gates Brook subwatershed can be applied to other subwatersheds in the Wachusett drainage basin.

2.0 STUDY AREA DESCRIPTION

2.1 Wachusett Reservoir

Wachusett Reservoir is located in the South Branch of the Nashua River upstream of the Town of Clinton, Massachusetts. The reservoir was constructed over the period from 1896 to 1908, when over 7.6 square miles of land was acquired and flooded to create a reservoir. Wachusett Reservoir was the principal water supply reservoir for the metropolitan Boston area prior to construction of the Quabbin Reservoir in the 1930's. Only about one-third of the water demand for Boston and the surrounding communities is met by runoff from the Wachusett watershed. The additional two-thirds of the demand is met by transfers to Wachusett from the Quabbin system west of Wachusett. All water which supplies metropolitan Boston must pass through Wachusett Reservoir which is currently an unfiltered supply. Therefore, the water quality of the entire water supply system is impacted by conditions in the Wachusett drainage basin. The watershed system is shown in **Figure 2-1**.

The Wachusett Reservoir has a watershed of approximately 117 square miles, which includes portions of 12 communities. The reservoir's surface area is 3960 acres (6.18 square miles). The maximum reservoir depth is 126 feet and the mean depth is 44 feet. The maximum reservoir elevation is 395.00 feet BCB (Boston City Base). At maximum capacity, the volume of the reservoir is 65 billion gallons. The average withdrawal from the system is approximately 310 mgd. A study conducted in 1989 (CDM, 1989) estimated the average retention time to be approximately 0.5 years for the Wachusett Reservoir. The retention time, without the Quabbin diversion, was determined to be 1.3 years.

2.2 Gates Brook Subwatershed

Gates Brook is one of the smaller streams in the Wachusett drainage basin. The subwatershed for Gates Brook is 2028 acres (3.2 square miles), which is only three percent of the entire Wachusett Reservoir watershed. However, Gates Brook is the most urbanized subwatershed within the Wachusett Reservoir drainage basin. Approximately forty percent of the drainage area is developed for commercial, industrial, and residential use. Much of the developed area is adjacent to Gates Brook and in the lower portion of the subwatershed, in close proximity to the reservoir (MDC, 1990).

The headwaters of Gates Brook emanate from two distinct wetland systems. The more western wetland is in the southeast portion of Holden and the other wetland system is located in the southwest section of West Boylston (considered to be the drainage divide between the Gates Brook subwatershed and the Malden Brook subwatershed). The drainage from these two wetland systems join to form Gates Brook.

Approximately 70 percent of the Gates Brook subwatershed, as shown in **Figure 2-2,** is in West Boylston, 25 percent is in Holden, and 5 percent is in the City of Worcester. The Gates Brook subwatershed makes up approximately one-fifth of the land area of the town of West Boylston and flows through a highly urbanized section of the town. Runoff from several shopping plaza parking lots, a retail district, and a residential area that has the highest population density of the Wachusett watershed discharges directly to Gates Brook. Street sweeping and cleaning of catch basins is performed every one or two years by the Town of West Boylston. Many of the catch basins in the subwatershed, of which there are only a small number, were built without sumps.

FIGURE 2 - 1

GATES BROOK STORMWATER STUDY

Layout of MWRA/MDC Water System

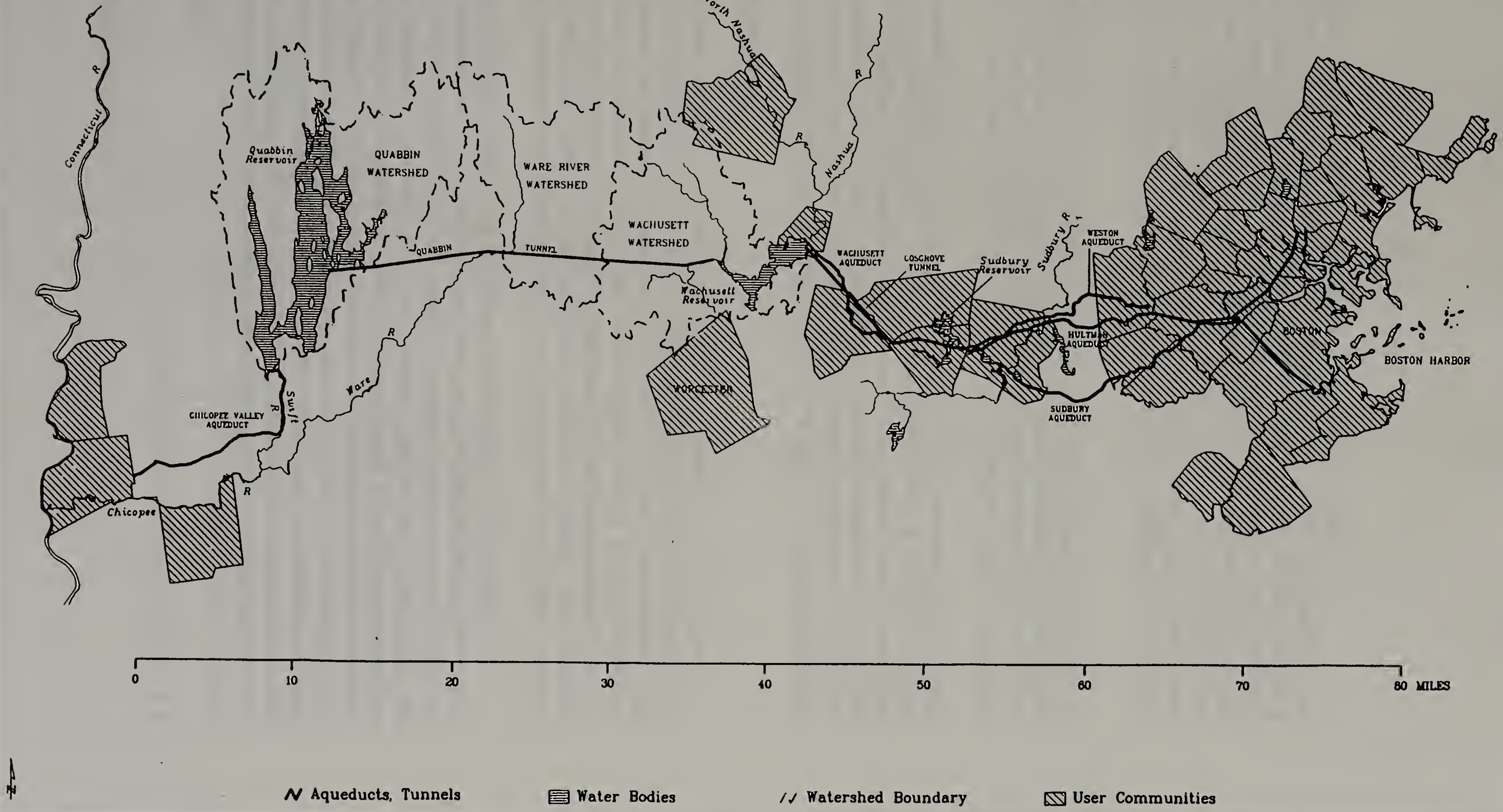
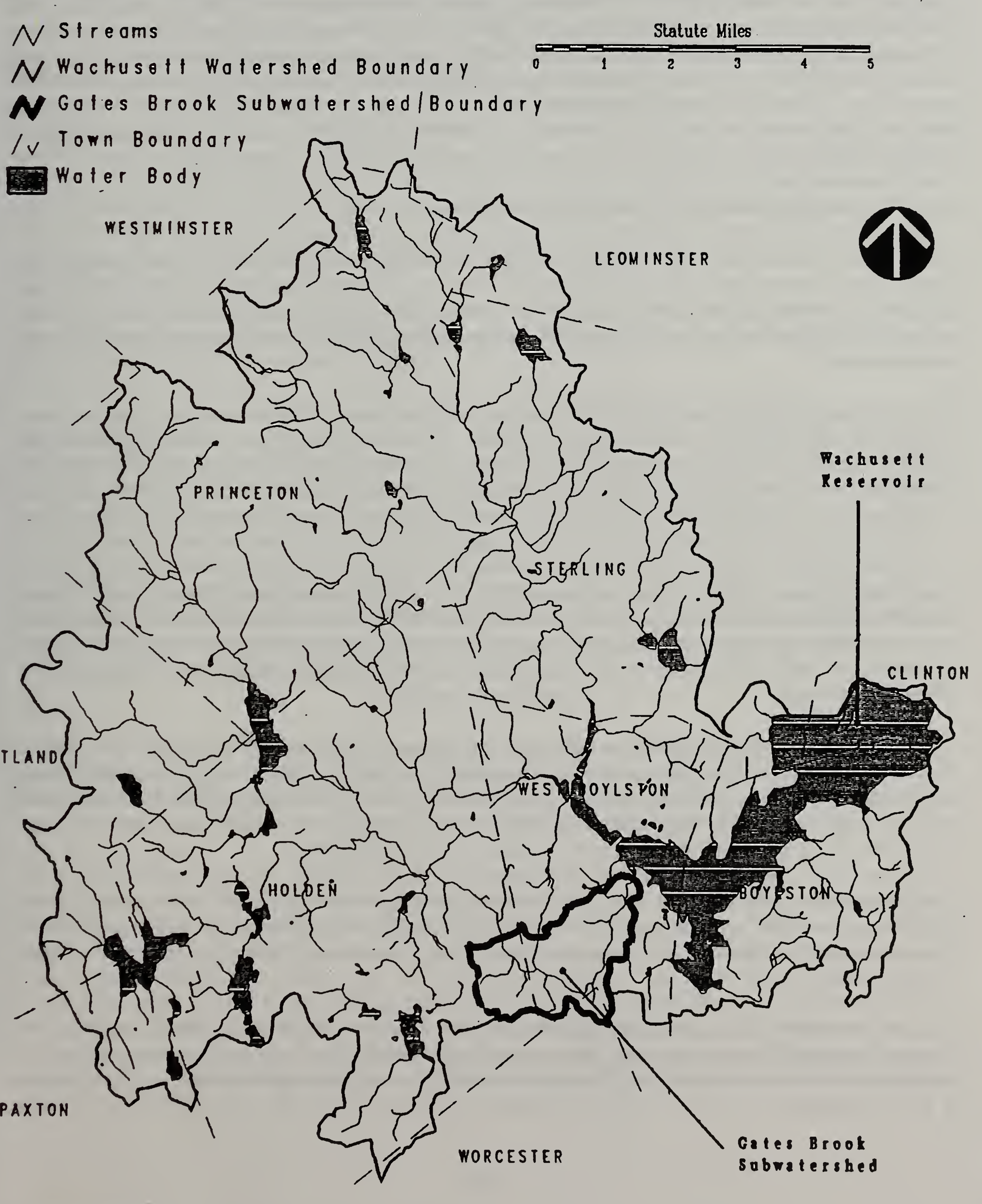


Figure 2-2

WACHUSETT WATERSHED: GATES BROOK SUBWATERSHED



None of the study area is served by publicly owned wastewater treatment systems. All wastewater disposal in the Gates Brook subwatershed is provided by on-site systems. Many of these systems were constructed prior to adoption of the current state regulations for design of subsurface disposal systems, 310 CMR 15.00 (Title 5). The soils in this area are primarily described as sandy loams and fine sandy loams. These soils are severely limited for subsurface sanitary disposal because of either extremely rapid permeability or very slow permeability with perched groundwater tables (Taylor and Holtz, 1985). Many of the existing systems are merely stone cesspools and on lots smaller than 20,000 square feet. There are several commercial sites in the area which also utilize on-site wastewater disposal. The overall septic system density in the subwatershed is 93 systems per 100 acres (Tighe & Bond, 1989).

2.3 Natural Features and Physical Characteristics

Gates Brook subwatershed has highly varied physical characteristics. The headwaters of Gates Brook are located in an area of wetlands. The brook is fed by a number of smaller tributaries, discharges from detention basins and storm drains and overland flow. The down gradient portion of the subwatershed is the most densely developed, and includes the bulk of the impervious area within the subwatershed.

The topography of the Gates Brook subwatershed includes rolling hills with some steep slopes, areas of exposed bedrock, and pockets of large wetlands. Elevations range from 386 feet at the surface of the reservoir to 850 feet on Drury Hill in Holden. There are some areas with slopes in excess of fifteen percent. The natural vegetative cover is primarily hardwood and mixed hard/softwood forest.

Soils

The Gates Brook subwatershed is dominated by Hinckley-Merrimac-Windsor and Paxton-Woodbridge-Canton soil associations (Taylor and Holtz, 1985). Hinckley-Merrimac-Windsor soils are deep, somewhat excessively drained and formed on well-sorted deposits of glacial outwash. Paxton-Woodbridge-Canton soils are deep, well-drained to moderately well-drained and are formed on glacial till in upland areas.

The predominant soils are Hinkley sandy loam, Merrimac fine sandy loam and Paxton fine sandy loam. All of these soil types are qualified as severely limited for subsurface sanitary disposal (Taylor and Holtz, 1985). The permeability of the Hinkley sandy loam and the Merrimac fine sandy loam is rapid in the subsoil and very rapid in the substratum. The soils are a poor filter for septic tank absorption fields due to the poor filtering capacity of the substratum.

The Paxton fine sandy loam has moderate permeability in the subsoil and very slow permeability in the substratum. The subsoil is formed from friable glacial till and the substratum is very firm glacial till. As a result, seasonal perched high water tables are associated with this type of soil at depths of 1-1/2 to 3 feet.

The soil erodibility factor K specified in the Universal Soil Loss Equation (USLE) indicates the inherent erodibility due to sheet and rill erosion (Brady, 1990). The five most common soil types in the Gates Brook subwatershed have K values between 0.10 and 0.32, suggesting that erosion potential is low to moderate.

Hydrology

The annual precipitation data for the 35-year period of 1955 to 1990 ranges from 31.06 to 64.07 inches (MWRA, 1990). The average annual precipitation from 1897 to 1990, measured at the gaging station maintained by the MDC, was 47 inches. Fifty percent, or 23.5 inches is typically assumed to evaporate or transpire (Brackley and Hansen, 1977). The remainder, therefore, enters the reservoir as surface runoff or groundwater. Precipitation is equally distributed throughout the year.

Gates Brook base flow was measured as part of an earlier watershed-wide study to estimate the nutrient loads to the reservoir. The mean stream flow measured from April 1988 through March 1989 was 5.65 cfs, with a range of 0.39 to 21.21 cfs (CDM, 1989). However, these flow measurements were all recorded during dry weather conditions. Flow measurements taken during the stormwater study described in this report occasionally exceeded 154 cfs. The annual yield of the subwatershed was estimated to be 1073 million gallons (CDM, 1989).

About thirty percent of the underlying geology contains an unconsolidated aquifer capable of yielding up to 100 gallons per minute (Brackley and Hansen, 1977). The remainder is typically till with potential yields of up to 10 gallons per minute.

2.4 Demographics

The general pattern of development for the Gates Brook subwatershed has been observed to be relatively similar to the development patterns throughout the Town of West Boylston. Land use data for the Gates Brook subwatershed were obtained from the Massachusetts Executive Office of Environmental Affairs (EOEA) Geographical Information System (MASSGIS). The land use data were developed from photo-interpretation of aerial photographs taken in 1985. The available land use data can be divided into as many as 107 different land use categories. For this study, a retrieval was performed which aggregated land uses into 15 groups as reported in **Table 2-1**.

Historical Land Uses

In 1985, the major land use categories were residential and forest. Roughly equal amounts of land were in these two categories; 37 percent and 36 percent, respectively. The third largest land use was Commercial/Urban Transportation, which accounted for another 12 percent of the land use. The remainder was Open Space/Recreation at 8 percent, and Agriculture at 7 percent.

The Central Massachusetts Regional Planning Commission conducted a detailed land use and planning study for the Town of West Boylston in 1979 (CMRPC, 1979). The study found that fifty three (53) percent of West Boylston was in a forested land use, nineteen (19) percent was in agricultural use or open space, sixteen (16) percent was in urban development, nine (9) percent was in wetlands, and three (3) percent was as utility right of ways. This study also compared aerial photographs taken in 1971 to establish land uses with land use data from 1951. The data in the 1979 study suggest that the town converted less than one percent of its forest land use to development, but during the same period, 37 percent of its agricultural and open space, and 8 percent of the wetland were converted to developed areas. Urban development increased 236 percent during the period from 1951 through 1971 (MacConnell and Niedzwiedz, 1974).

TABLE 2-1

Gates Brook Subwatershed Land Uses

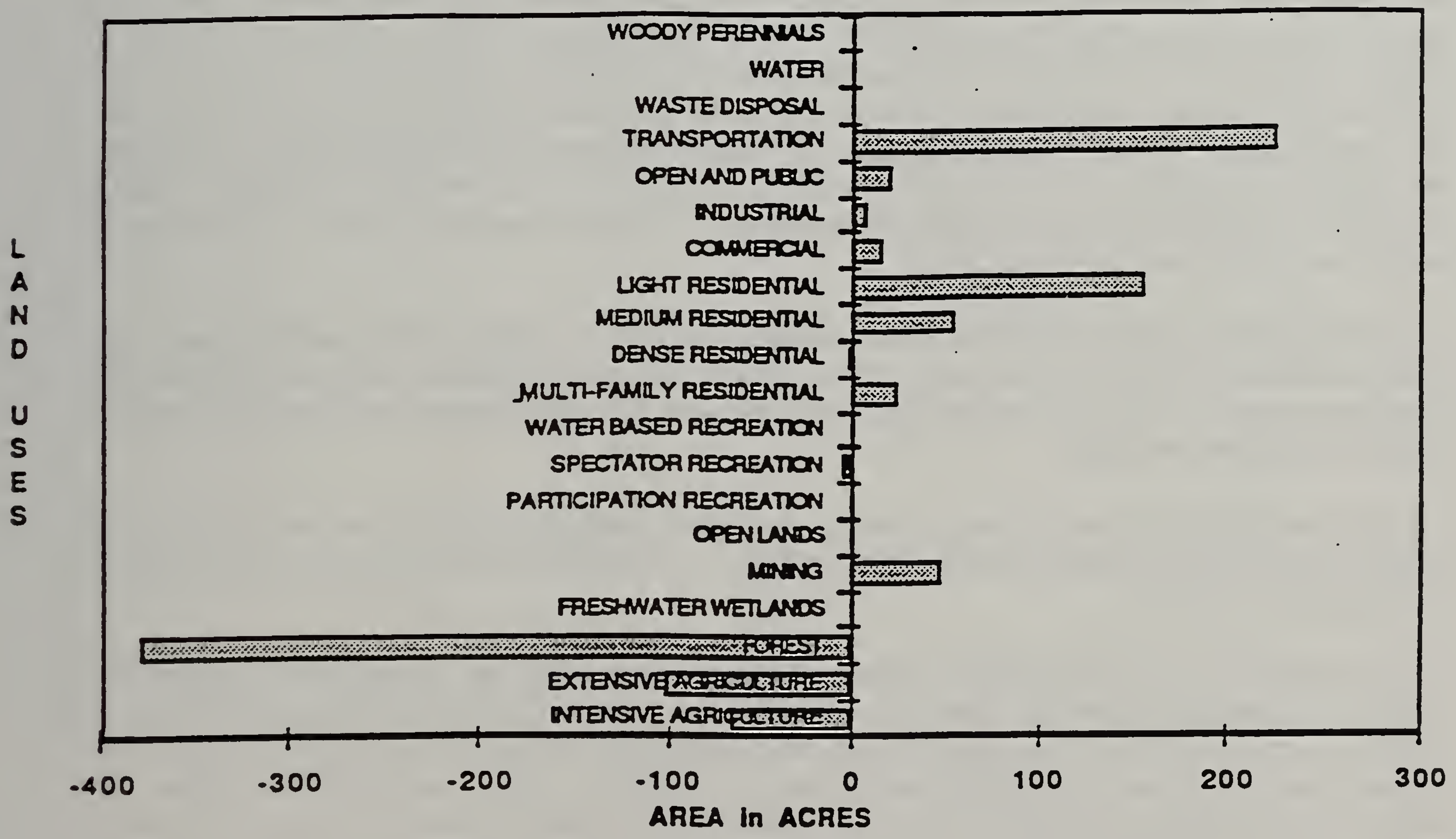
CATEGORY - LAND USE	AREA (Acres)	AREA (Percent)
Cropland	81.0	4.0
Pasture	50.8	2.5
Forest	726	36
Wetland	17.5	4.3
Open Land	41.6	2
Participation Recreation	88.2	4.3
Spectator Recreation	16.5	0.8
Residential, Multi-family	9	0.4
Residential, < 1/4 acre	296.1	14.6
Residential, 1/4 to 1/2 acre	382.2	18.9
Residential, > 1/2 acre	80.6	3.9
Commercial	101.6	5
Urban Open	42.5	2.1
Transportation	88.3	4.3
Woody Perennial	6.1	0.3
TOTALS	2028	100

Changes in land uses throughout West Boylston from 1971 to 1985 are displayed graphically in **Figure 2-3** (Fabos et al., 1990). This figure shows that there has been additional loss of forest and other open space since the CMRPC report was prepared. The largest change in land use category for this period was in transportation. Approximately 225 acres of land were converted to transportation use. The majority of this land change was associated with the construction of Interstate Highway Route I-190. The second largest increase in land use was in the category of residential use having lot areas greater than twenty-thousand square feet.

FIGURE 2 - 3

GATES BROOK STORMWATER STUDY

West Boylston Land Use Changes 1971 - 1985*



* Source: Fabos, et al, 1990

The changes in land use from the 1950's to the present in West Boylston reflect those seen in much of the Commonwealth. During this period, large tracts of open space were converted for residential and urban use. Although the studies cited in the previous paragraphs do not use consistent land use categories nor are they specific to the subwatershed, it is evident that significant changes in land use and development have occurred in the Gates Brook subwatershed during the past forty years.

An important consideration when reviewing land use patterns and their impact on water quality is that much of the retail/commercial and residential use is in close proximity to Gates Brook. Developed areas are generally considered to have a detrimental effect on water quality, when compared to natural conditions. Since the developed areas in this subwatershed are in the area nearest the reservoir, it is more likely that negative impacts to water quality will be more pronounced than if the developed uses were spread throughout the subwatershed.

Zoning

There are four zoning classifications within the Gates Brook subwatershed: single-family residential in West Boylston and Holden, general residential, and business. Single-family residential zoning comprises most of the area, with bands of general residence zoning and business zoning for land along Route 12 and Route 140.

The single-family residential zoning category within West Boylston allows agricultural uses, single family dwellings, schools, libraries, and churches. A minimum lot area of 40,000 square feet with 120 feet of frontage is required by the Zoning By-laws in West Boylston. Of the 1662 homes existing in 1986 only 22 percent met the 40,000 square foot area requirement. Twenty-six (26) percent were on 20,000 to 40,000 square foot lots, and 52 percent were on lots under 20,000 square feet (MDC, 1990). The single-family residential zoning category in Holden allows single-family dwellings, agriculture, and religious institutions with a minimum lot area of 10,000 sf., and 64 feet of frontage. Single residential lots within the Gates Brook subwatershed in Holden range from 10,000 to 20,000 square feet in area (MDC and MWRA, 1991b).

General residential zoning allows the same uses and requires the same lot size and frontage as the single residential district, but also permits multi-family homes, apartments, and hotels/motels. No more than twelve units per apartment complex are allowed, and multi-family homes must have at least 20,000 square feet per family.

The business district allows the same uses as the single residential district but also allows retail business, offices, and commercial amusement facilities. A minimum lot size of one acre with 150 feet of frontage is required.

Requirements in two overlay districts create additional controls for use and minimum dimensional criteria. A Floodplain Overlay District is based on the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps of the one-hundred-year storm event flood elevations. The requirements of this overlay prohibit construction in a floodplain without compensatory volume. An Aquifer and Watershed Protection District is based on the recharge potential to the town's wells. This District prohibits manufacturing, storage and/or use of hazardous substances (except incidental to domestic use), trucking terminals, storage or use of ice control chemicals (except by the town), dumping of snow not associated with that accumulated on the lot, vehicle sale, servicing, repairs, or painting, commercial or industrial discharges; underground storage tanks; or landfills. Additionally, the minimum lot size of fifty thousand square feet and 150 feet of frontage is required per lot, with a maximum of fifteen percent of the lot allowed to be made impermeable.

Population

The population of West Boylston increased 144 percent between 1950 and 1975, and peaked in 1975 at 6,256. The population decreased to 6,054 in 1988, and from current town clerk records, has stabilized at 6,025. Residential construction peaked in 1986 when 36 single family homes were built.

The population of Holden experienced a substantial increase (127%) from 1950 through 1975, then peaked in 1990 at 14,747 people. The most current census reports indicate Holden's population to be 14,628, with an annual growth of nine percent over the last fifteen years

The Gates Brook subwatershed as of 1988 had 1641 homes with 5071 inhabitants (Tighe & Bond, 1989). The population density in 1988 was estimated to be 2.5 persons per acre. This is one of the most densely populated subwatersheds within the MDC system.

3.0 STORMWATER SAMPLING PROGRAM

3.1 Site Selection

The MDC and DEP determined that the initial stormwater program should focus on a single tributary with significant stormwater impacts. The Gates Brook subwatershed was chosen as the area for initial stormwater sampling, because of evidence of pollutant loading found in previous water quality sampling and analysis conducted by MDC Environmental Quality Section (EQS) staff. The EQS sampling had documented Gates Brook to be one of the most severely polluted streams in the Wachusett watershed. **Table 3-1** summarizes the range of values which were documented by EQS from 1982 through 1990.

3.2 Study Period

The wet weather sampling program goal was to collect data from two or three representative storms during each season, over a one year period. A one year sampling regime was selected in order to collect seasonal conditions, to assess possibly significant seasonal variations in stormwater pollutant loading. The equipment preparation and design started in August of 1990 and the actual sampling was conducted from October, 1990 through October, 1991.

3.3 Sampling Station Location and Installation

EQS staff were quite familiar with the stream, due to extensive sampling work which had been previously conducted along its entire length (MDC, 1990). Some additional reconnaissance was conducted in order to evaluate sampling locations.

There are no formal stormwater drainage systems in the Gates Brook subwatershed, which in conventional stormwater studies are sampled directly to obtain data. For this study, storm samples were collected from the receiving water. Thus, the stormwater which was sampled represented the storm runoff diluted with the base flow of the receiving water.

A sampling station was selected at an existing 48-inch diameter concrete culvert under the "Gate 25 access road" on MDC land in West Boylston. This location is approximately 100 yards above the confluence of the brook with the reservoir.

The station also allowed good sampling access in any weather; the road was passable in a 4-wheel drive truck during rain or snow and the MDC plowed as far as the station after heavy snow. The sampling location was far enough from the road to minimize the possibility of vandalism. A weatherproof sampling hut was built on a concrete pad to protect and store the flow meter and automatic sampling equipment. The sampling hose and flow meter cables were threaded through a 4-inch PVC pipe bolted to the stone bridge.

TABLE 3 - 1

GATES BROOK STORMWATER STUDY

Water Quality Monitoring Data
Range of Values Observed 1982 - 1990

(All units in mg/l unless noted)

Parameter	Value
pH (SU)	6.6 - 7.9
Alkalinity (as $CaCO_3$)	12 - 64
Hardness (as $CaCO_3$)	18 - 105
Turbity (NTU)	0.25 - 95
Color (Color units)	5 - 56
Conductivity (μmhos/cm)	71 - 550
Chloride	21 - 207
Total Kjeldahl-Nitrogen	0.14 - 0.5
Ammonia-Nitrogen	0.019 - 0.11
Nitrate & Nitrate-Nitrogen	0.9 - 2.5
Total Phosphorus	0.013 - 0.138
Orthophosphate	0.012 - 0.119
Silica	2.2 - 4.0
Total Coliform Bacteria (colonies/100 ml)	20 - 4600
Fecal Coliform Bacteria (colonies/100 ml)	16 - 3900

(8290valu)

Automatic Sampler

Unmanned collection of water quality samples was accomplished by using an ISCO Model 3700 automatic sampler which can collect uniform or non-uniform, time-based or flow-based samples. The strainer intake for the ISCO was placed on the downstream side of the culvert. The sampling plan called for using a liquid level actuator to initiate the automatic sampling routine. Stream stage was variable under dry weather conditions, which routinely inadvertently triggered the sampler. The time to begin sampling therefore had to be set manually and was set based on storm predictions from the NOAA weather station in Worcester. This procedure was followed when the criteria for antecedent dry days was met as specified below.

Flow Gage

An existing 48" concrete culvert was chosen as the gaging location, which had a slope of 0.018 feet per foot and a length of 16 feet. The flow in the culvert was calculated using Manning's equation based on the water depth measured in the culvert. Continuous flow data were recorded on a strip chart from an ISCO Model 3220 submerged probe liquid monitoring device installed directly within the culvert. The submerged probe converts the hydrostatic pressure of water over the probe to a water depth.

Three storms were sampled before the flow meter was installed. During the storms in October through December, the water depth was measured and recorded by the sampling crew as the water quality samples were collected. For storm events occurring after December 4, flow data was recorded by the flow meter until the storm event on March 2, when the flow meter probe was damaged by debris transported in the brook. The flow meter was inoperative from March through May until the replacement probe was installed.

Rain Gage

A weighing-bucket rain gage was installed at the Gates Brook sampling site to collect rainfall data for the specific events sampled. Due to problems encountered in the field with operation of the weighing bucket rain gage, not all of the storms sampled had corresponding precipitation data. Alternative rainfall information was therefore necessary to assure calibration of the model. A comparison was made between data collected from the weighing-bucket rain gage and an existing rain gage operated by a local volunteer located in the subwatershed. These data correlated within acceptable limits.

Comparison was also made between precipitation data collected from the existing rain gage and an established National Oceanographic and Atmospheric Administration (NOAA) precipitation gaging station (number 199923), located at Worcester Airport, Massachusetts, approximately eight miles from the sampling station. Daily and hourly precipitation records were available from this station. The NOAA data compared acceptably and was the most detailed and reliable information available for the study. A comparison of the rainfall data is depicted in **Table 3-2**

TABLE 3 - 2

GATES BROOK STORMWATER STUDY

Comparison of NOAA Records and Gates Brook Rain Gage Data (inches)
(Sampled storms are shaded)

Storm Date	NOAA Record	Gates Brook Record	MDC Holden Record
02/14/91	0.83	1.10	0.34
02/19/91	0.26	0.30	0.39
03/18/91	0.29	0.27*	0.34
03/21/91	0.02	0.05	0.03
03/22/91	0.46	0.50	0.41
03/23/91	0.58	0.45	0.45
03/24/91	0.27	0.20	0.19
03/25/91	T	0.00	0.02
03/27/91	0.06	0.04	0.06
03/29/91	0.10	0.15	0.05
03/30/91	0.10	0.15	0.08
04/30/91	1.69	1.50	1.75
05/06/91	1.84	1.65	1.65
05/10/91	0.10	T	0.01
05/14/91	0.13	0.05	0.05
05/17/91	0.44	0.70	0.55
05/18/91	0.07	0.04	NR
05/27/91	0.33	0.78	1.00
05/30/91	0.68	0.35	0.36
05/31/91	0.31	0.30	0.35
06/03/91	0.01	0.05	0.11
06/04/91	0.07	0.03	0.15
06/08/91	0.07	T	0.03
06/11/91	0.06	0.25	0.08
06/12/91	0.48	0.32	0.38
06/15/91	0.40	T	0.55
06/16/91	0.82	1.00	0.53
06/17/91	T	0.00	0.02
06/19/91	0.55	0.15	0.18
06/22/91	0.02	0.02	0.03
06/29/91	0.00	0.00	0.36
06/30/91	0.51	0.72	0.32
07/02/91	0.00	0.00	0.10
07/03/91	0.02	0.02	0.02
07/05/91	0.05	0.05	0.06
07/06/91	T	0.00	0.77

TABLE 3 - 2 (cont)

GATES BROOK STORMWATER STUDY

Comparison of NOAA Records and Gates Brook Rain Gage Data (inches)
(Sampled storms are shaded)

Storm Date	NOAA Record	Gates Brook Record	MDC Holden Record
07/07/91	0.06	0.55	0.02
07/13/91	0.41	0.47	0.46
07/23/91	0.19	0.30	0.21
07/25/91	0.13	0.35	0.48
07/26/91	1.75	1.10	1.45
07/27/91	0.13	0.15	0.01
08/03/91	0.09	0.05	0.14
08/04/91	0.14	0.02	0.19
08/09/91	0.68	0.70	1.45
08/10/91	0.71	0.72	0.02
08/15/91	0.30	0.40	0.41
08/18/91	T	0.67	1.10
08/19/91	5.00	4.40	4.51
08/20/91	0.40	0.18	0.51
08/21/91	0.57	0.45	0.02
08/30/91	0.00	0.00	0.02
08/31/91	0.12	0.28	0.21
09/01/91	0.00	0.28	
09/05/91	0.90	0.65	

* Storm continued past midnight of first day.
NR - No record
T - Trace

3.4 Stormwater Sample Collection and Analysis

Collection of water quality samples and flow data during a storm event required advance preparation to have all necessary equipment available, and notification of the laboratory that samples would be delivered for water quality analysis. Field staff had to be notified, as well, to be available for sampling. The project team followed weather predictions throughout the project, and would make the decision to try to sample a predicted event.

The time between storm events is the period when pollutants accumulate on impervious surfaces and on the soil. As the storm runoff moves over the surface and infiltrates through the soil, the accumulated dry weather solids are carried into the brook. A review of the rainfall data at the Worcester NOAA station for the year 1990 showed that the number of "dry" days between storms (days with less than .01 inches of precipitation) was as great as 13 days. The average number of consecutive dry days was 3.7 days, while 68 percent of the time precipitation was recorded every 2 or 3 days. A criterion of three antecedent dry days for sample collection was selected. An antecedent dry day for this study was defined as a day with less than 0.05 inches of precipitation. **Table 3-3** summarizes the precipitation data and antecedent dry days for the storms sampled.

Exceptions were made to the antecedent dry day standard when there had been very light rainfall with little runoff a few days before a predicted rainfall event. Specifically, samples were taken for the following when the criterion was not met: two days before the May 30 and June 11 storms it rained 0.07 inches; the June 12 storm had less than 0.1 inches of rain per day for 10 days prior to sampling the 0.48 inch storm event; a steady drizzle (0.17 inches) during December 16 was excepted from the criteria for the December 18 storm; the September 25 storm had a total of 0.15 inches of rain during the preceding four days. Of the exceptions to the antecedent dry day criterion, only the May 30 and June 11 events were used for modelling.

Pollutant concentrations vary greatly in stormwater runoff. The concentrations are affected by a variety of parameters, including antecedent weather conditions, rainfall intensity, and time of concentration of the watershed. In order to accurately characterize the stormwater quality, a series of discrete samples are collected, at appropriate time intervals over the entire storm event. Typically, the number of discrete samples which can be collected is controlled by the sampling equipment.

Sampling protocol was initially set up to obtain first flush characteristics. The protocol called for collection of discrete samples every ten minutes for the first thirty minutes, every fifteen minutes for the next ninety minutes, every thirty minutes for the next two hours, and then hourly until all available bottles were filled. Two one-liter bottles were filled per sample to obtain adequate sample volume for all analytes. The sampler was automatically triggered using the ISCO Model 1640 liquid level actuator. The device was set to begin sampling automatically at a specified water elevation.

The sampling program was modified in April, 1991. The reason for the change was the initial protocol only collected data from the first three hours of an event due to the limited number of sample bottles (24). Review of sampled storm events prior to mid-February suggested that the event durations ranged from thirty to forty hours. The revised protocol called for collection of 300 ml samples collected at twenty minute intervals over a two hour period into two liter samples. The new protocol enabled the collection of twenty-four hours of data (twelve samples of two bottles per sample).

The protocol was again revised in June of 1991 to collect one hour composite samples consisting of four 500 ml samples taken at fifteen minute intervals. This change was made to provide more definition to the variation during the storm event. An additional ISCO 3700 sampler, obtained from the DEP containing 24 bottles, was installed in series to allow for twenty-four hours of automatic sampling.

TABLE 3 - 3

GATES BROOK STORMWATER STUDY

Antecedent Dry Period Assessment

Date	Precipitation (in)[1]	Antecedent Dry Days	Met Dry Criteria for Model
08/23/90[2]	0	3	Y
10/15/90[2]	0	1	Y
10/23/90	1.62	3	Y
12/04/90	2.12	4	Y
12/18/90	0.32	1	N
01/16/91	0.57	3	Y
02/04/91[3]	0	3	Y
02/07/91	0.71	6	Y
04/30/91	1.69	7	Y
05/21/91[2]	0	3	Y
05/30/91	0.68	2	Y
05/31/91[4]	0.31	-	-
06/05/91	0.07	0[5]	N
06/11/91	0.06	2	Y
06/12/91	0.48	0[6]	N
06/19/91	0.55	2	Y
06/25/91[2]	0	3	Y
07/23/91	0.19	9	Y
08/19/91	5.00	3	Y
09/19/91	0.43	3	Y
09/25/91	3.06	1	Y
10/15/91	0.23	3	Y

[1] Measured at NOAA gage, Worcester, MA
[2] Dry weather sample
[3] Snow melt during dry weather
[4] Continuation of 5/30/91 storm
[5] During third day of light continuous rain
[6] Previous day's rain was light

(strmppt)

3.4.1 Water Quality Parameters

The sampling program at Gates Brook was intended to determine the levels of nutrients and bacteria which may cause water quality excursions outside the surface water quality standards, drinking water standards, and/or cause taste and odor problems. Samples were analyzed for total phosphorus, total Kjeldahl nitrogen, nitrate-nitrogen, ammonia-nitrogen, turbidity, total and suspended solids, total volatile solids, pH, conductivity, alkalinity, hardness, chlorides, and fecal coliform bacteria. Samples from the first 11 storms were also analyzed for 12 metals: iron, manganese, calcium, aluminum, copper, zinc, lead, chromium, cadmium, nickel, arsenic, and mercury. These parameters were chosen based on a comparison with MDC data collected during routine monitoring at this station, previous studies by Tighe & Bond (1989) and CDM (1989), and their accepted use in similar regional and nationwide stormwater studies.

3.4.2 Sampling and Laboratory Procedures

Water quality samples were collected in accordance with all approved protocols and within appropriate holding times. Sampling procedures are detailed in DWPC/TSS Basin Program Standard Operating Procedures for River and Stream Monitoring (DWPC, 1989) and summarized in **Appendix A**.

Water quality analyses were conducted according to approved U. S. Environmental Protection Agency and Massachusetts DEP laboratory methods (MDEP,1989b). Water quality analyses for three storms were conducted by laboratories under contract with the MDC. Samples collected on June 12, 1991 and on June 19, 1991 were analyzed by Lycott Laboratory in Southbridge, Massachusetts. Samples collected on September 25, 1992 were analyzed by Revet Laboratory, in Worcester, Massachusetts. All other water quality analyses were performed at the DEP Lawrence Experiment Station (LES), in Lawrence, MA. The methods of analysis used by LES and the corresponding limit of detection for each analyte are reported in **Appendix A**. The water quality data, on spreadsheets (Borland International, 1989) is in **Appendix B**.

Bacterial samples were collected using sterile techniques. Therefore, bacteria samples could not be collected with an automatic sampler, and required manual collection. Because of this limitation, the set of bacteria data is limited with respect to the other parameters. Bacteria analyses were conducted at the MDC water quality laboratory in Clinton.

3.5 Stormwater Sampling Results

The objective of the stormwater sampling plan was to collect both water quality and flow data from storm events. Twenty-six events were sampled as part of this program. For some of the storms, both sets of data were not collected because of certain sampling limitations. **Table 3-4** summarizes data collected for each storm event, and ranges of values documented for the water quality parameters as well as the concentrations of selected metals in the samples.

Water quality data were collected before the flow meter was installed. Water quality data were collected for three storms prior to installation of the flow meter in December. Readings of the gage were recorded by staff when the water quality samples were collected from October through

TABLE 3 - 4

GATES BROOK STORMWATER STUDY

Summary of Analysis for Selected Water Quality Paramenters

Date	Precip (ins)	Ant Dry (days)	Base Flow (cfs)	Peak Flow (cfs)	Total Storm Vol (ac-ft)	Total Solids (mg/l)			Suspended Solids (mg/l)			Total Phosphorus (µg/l)		
						Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
08/23/90[1]	0	3						234[4]			<1[4]			–
10/15/90[2]	0	1				180	170	178	2	<1	1	46	37	41
10/23/90	1.62	3				230	210	210	2	<1	1	34	23	28
12/04/90	2.12	4				354	124	203	300	1	74	2,100	16	381
12/18/90	0.32	1				208	196	203	3	2	2	27	13	19
12/23/90	0.57	3				–	–	–	–	–	–	–	–	–
12/30/90	0.35	0			67.0	–	–	–	–	–	–	–	–	–
01/11/91	0.35	1				–	–	–	–	–	–	–	–	–
01/12/90	0.51	0				–	–	–	–	–	–	–	–	–
01/16/91	0.57	3	9.0	35.4	44.1	1176	406	821	76	2	23	290	24	94
01/30/91	0.37	0			57.3	–	–	–	–	–	–	–	–	–
02/04/91[3]	0	3				286	200	221	21	1	7	69	18	36
02/07/91	0.71	6	7.0	50.8	89.1	232	170	203	78	1	21	270	25	86
04/30/91	1.69	7				400	162	211	346	4	47	620	32	114
05/21/91[2]	0	3				248	226	236	3	<1	2	27	10	16
05/30/91	0.68	2	3.3	13.9	1.98	282	104	205	63	2	17	200	14	68
06/05/91	0.07	0[5]						234[4]			2[4]			18[4]
06/11/91	0.06	2	3.9	21.6	1.95	386	158	219	226	<1	42	570	17	141
06/12/91	0.48	0[6]		29.3	4.67	312	80	238	160	14	77	291	<5	123
06/19/91	0.55	2	2.6	20.0	5.14	294	180	254	72	2	25	268	<5	65
06/25/91[2]	0	3						238[4]			2[4]			20[4]
07/23/90	0.19	9	0.8	3.8	0.85	432	124	216	42	6	17	160	40	99
08/19/91	5.0	3				3112	126	432	265	5.5	83	860	80	290
09/20/91	0.43	3	0.1	8.5	7.87	476	126	234	70	1	11	250	30	71
09/25/91	3.06	1	1.54	76.3	171.9	244	99	183	133	<1	37	66	20	37
10/15/91	0.23	3		2.3		268	156	221	1.5	<1	1	28	7	16

[1] Dry weather sample
[2] Dry weather composite
[3] Snow melt during dry weather
[4] Single sample collected
[5] During third day of light continuous rain
[6] Previous day's rain was light

(sumstdat)

December. For storm events occurring after December fourth, flow data were recorded by the flow meter until the storm event on March 2, when the flow meter probe was damaged by debris transported in the brook. The flow meter was inoperative from March through May until the replacement probe was installed.

3.6 Water Quality Data

The data collected in this program provide an extensive stormwater water quality data base for Gates Brook. This section provides a brief qualitative discussion of the results of water quality testing. The discussions have been drawn from Standard Methods (APHA, 1985), Quality Criteria for Water (USEPA, 1986), Water Chemistry (Snoeyink and Jenkins, 1980), Drinking Water and Health (National Research Council, 1977) and Controlling Urban Runoff (Schueler, 1987).

The results of the stormwater sampling are compared with the USEPA water quality criteria and drinking water standards. The Water Quality Criteria were established under the authority of Section 304(a) of the Federal Clean Water Act to protect aquatic life and reflect human health concerns. Limits are referenced from the Mass. Surface Water Quality Standards, 314 CMR 4(MADEP, 1990).

Although the stormwater samples do not represent finished drinking water, they are a source of contaminants to the supply. The drinking water standards are promulgated by the USEPA under the authority of the Safe Drinking Water Act. The Division of Water Supply in DEP, as primacy agent under the Act, regulates drinking water quality through its regulations in 310 CMR 22. The regulations set standards and water quality monitoring requirements in accordance with the national Interim Primary Drinking Water Regulations. Under these regulations, compliance monitoring (except for turbidity) is to be performed on water samples which are representative of that supplied to the consumer, which requires that analyses be conducted on finished water samples.

The USEPA primary standard for drinking water, the Maximum Contaminant Level (MCL) is the highest allowable amount of a contaminant in drinking water supplied by municipal systems. MCLs are developed for proven and probable carcinogens and other toxic compounds. MCLs are set for particular contaminants when they occur in drinking water supplies; or they are expected to threaten public health; and they can be detected in drinking water by current laboratory methods (Stewart et al, 1989). Primary MCLs are enforceable, health-based standards for inorganic contaminants, volatile organic contaminants, bacteria, turbidity, and radiological contaminants.

Secondary Maximum Contaminant Levels (SMCL) are non-enforceable taste, odor and appearance guidelines. Chloride, iron, manganese, pH, total dissolved solids (TDS), and zinc have SMCLs.

Minerals

The carbonate and pH system are important factors in the chemical and biological systems of natural waters. Photosynthesis and respiration, buffering capacity, solubility of metal compounds, and toxicity are affected by the degree of disassociation of weak acids and bases indicated by pH.

The federal secondary drinking water standard for pH is from 6.5 to 8.5. The pH of water supplies affects pipe corrosion and leaching of metals into the water supply, and treatment processes of coagulation, filtration, and chlorination. The USEPA " Gold Book" aquatic life criteria for fish is pH

6.5 to 9.0, although the toxicity of other substances may change in that range (USEPA, 1986b). The pH during storm events was 6.1 to 7.7.

Alkalinity is a measure of the capacity of water to neutralize strong acid. This buffering capacity is important because pH has a direct effect on aquatic organisms and indirect effect on the toxicity of other compounds. Alkalinity buffers that pH changes occurs naturally as the result of photosynthesis and protects fish and other aquatic life from fluctuating pH. Carbonate and bicarbonate species will also complex heavy metals and reduce their toxicity by lowering the concentration of the free metal ion.

The alkalinity of water supplies affects coagulation treatment processes and corrosion control. The buffering capacity of the water neutralizes the excess acid produced when aluminum sulfate or other coagulants are added.

When alkalinity is attributed to naturally occurring materials such as bicarbonate and carbonate, levels up to 400 mg/l are not considered to be a human health problem (NAS, 1974). 20 mg/l is the freshwater aquatic life criterion (USEPA, 1986b). The alkalinity at Gates Brook during routine sampling ranged from 12 to 64 mg/l, while the study's samples ranged from 14 to 49 mg/l.

Hardness is the sum of polyvalent cations present in water. Hardness is reported as the equivalent amount calcium carbonate ($CaCO_3$). The most common ions are calcium and magnesium, but iron, strontium, and manganese can also contribute. Since rainwater is naturally acid, percolation through limestone rock is a natural source of hardness.

Water hardness also affects the toxicity of metal heavy metal ions on fish and other aquatic organisms. The reduction in toxicity may be caused by the ions causing hardness rather than hardness (USEPA, 1986b). The metal ions form complexes with carbonate and bicarbonate ions and are less toxic.

Cardiovascular diseases (heart disease, hypertension, and stroke) and other chronic diseases are associated with softwater (NRC, 1977). This may be due to the protective action of the elements found in hard water and the harmful effects of the metals in soft water.

There are no distinct boundaries between hard and soft water, although water below 75 mg/l is considered soft and 75 to 150 mg/l is moderately hard. Surface waters in the Northeast typically have low levels of hardness. During the sampled storm events, the range was 2 to 95 mg/l, and during routine monitoring the range was 18 to 105 mg/l.

Specific conductivity measurements provide an estimate of the amount of dissolved solids in solution. Conductivity often parallels chloride concentration and also give an indication of the overall water quality. Salting roads for ice control often results in high conductivity measurements. Drinking water conductivity levels range from 50 to 1500 µmhos/cm (AWWA, 1982). Conductivity at Gates Brook ranged from 53 to 1950 µmhos/cm. The highest level was recorded on January 16, reflecting road salting, and the lowest was during the hurricane, which may be a result of dilution.

Chlorides are introduced into streams after they are used for snow and ice removal. Because it is extremely soluble, almost all chloride applied for snow removal becomes dissolved in surface or ground waters (Pitt, 1985). Other sources are atmospheric deposition and geologic formations. At high levels, chlorides are toxic to many freshwater organisms.

Chloride is one of the most prevalent inorganic ions in water. The concentration that causes a salty taste depends in part on the associated cation. If the cation is sodium, the water will taste salty at 250 mg/l (APHA, 1985). But if the cation is calcium or magnesium, the water may not taste salty at 1000 mg/l. Persons with restricted salt diets should not drink high chloride waters, since chloride would be combined with sodium. The federal secondary drinking water standard is 250 mg/l to protect these interests.

The range of chloride concentrations for the sampled storm events was 18 to 530 mg/l. The highest level was recorded during the January 16 storm after the road had been salted following a snow storm. The highest level during routine sampling was 207 mg/l.

Solids

Stormwater runoff brings high concentrations of sediment into Gates Brook which increases the turbidity and reduces light penetration. Sediment particles carried along during storm events settle out when they reach a low velocity area or the storm flows abate. There they become a sink for organic matter, phosphorus, metals and other toxic pollutants adsorbed on the surface of the particles. Sediment oxygen demand (SOD) can reduce dissolved oxygen levels in overlying water. This sediment slowly moves through the stream as bedload, and covers the channel substrate with shifting deposits of mud and coarse sand. The sediment can clog the gills and filters of fish and aquatic organisms; destroy benthic habitat including spawning and nesting areas; and smother benthic organisms.

Uncontrolled construction sites have been shown to contribute approximately 40 tons/acre/year of sediment. Agricultural and stabilized urban land sediment loads, in contrast, are one and two orders of magnitude lower, respectively (Schueler, 1987).

Higher concentrations of suspended solids increase the scouring associated with stream flow and accelerate the undercutting of stream banks as seen in the lower portions of the brook. This exposes the roots of trees that protect and stabilize the bank. When this progressed to the point the trees lose their base strength and fall, the newly exposed material will erode further.

There is a large range of solids that are carried in stormwater (USEPA, 1976). The solids are both organic and inorganic. The inorganic component consists of clay, sand, gravel, weather concrete and pavement, and metal filings and pieces. Many of the inorganic solids in runoff are easily carried along because their specific gravity is close to that of water (USEPA, 1976). Included in this group are wood chips and fibers, leaf litter, grass clippings, seeds, pollen, organic fragments of peat and loam, and animal droppings. The organic particulates exert an oxygen demand as they decompose in Gates Brook and the reservoir. The amount of solids suspended or present in the water column is a reflection of the intensity and duration of the rainfall during each storm, the duration between storms, and the characteristics of the drainage area.

A number of different analytical methods were used to determine the concentration of particulate matter in Gates Brook. Total solids, suspended solids, total volatile solids, and turbidity each analysis target a different fraction of the particulate matter. High solids concentrations in drinking water cause undesirable physiological effects, an unpleasant mineral taste, and increase corrosion in piping, water heaters, toilet flushing mechanisms, and dishwashers and washing machines.

Total solids (TS) is determined by weighing the total residue from a sample following evaporation of a known amount. This measures the total residue present in both the dissolved and particulate form. One disadvantage of this method is that a single large particle can skew the results upwards. Most treatment devices for stormwater are designed to remove as much particulate material as possible, but dissolved materials are not filterable. If dissolved material is included in the analysis, it may reduce the usefulness of the analysis for predicting treatment efficiency. Dissolved solids are apt to be a greater proportion of total solids during the early spring thaw when deicing chemicals are washed off of roadways and other paved surfaces (USEPA, 1976).

Total solids concentrations of the sampled storms ranged from 99 to 3112 mg/l. The highest value was recorded during "Hurricane Bob" on August 19, 1991. The next highest concentration of 1176 mg/l during the January 16 storm may have been a result of the road sanding and salting during the snow storm the previous week. Outside of these two storms, the highest total solids concentration was 476 mg/l.

Suspended solids (SS) or nonfilterable residue is extensively used for characterizing storm flow. Suspended solids includes settleable solids and floatable solids. All dissolved solids and finely suspended and colloidal solids that cause turbidity are passed through the filter. Suspended solids shelter pathogens in areas that may not come in contact with chlorine disinfectant (NAS, 1974). Both the composition and concentration of suspended solids affect water treatment processes, and a raw water standard cannot be developed.

Suspended solids can effect fish and fish food populations by increased mortality or decreased growth rates, smothering fish eggs, changing movement and migration, and reducing food sources. Suspended solids also adsorb organic material such as pesticides, removing them from the water column and depositing them in the sediments (NAS, 1974). The smallest suspended particles, which may not settle out until they reach further into the reservoir, may have the highest concentration of metals and organo-chlorine insecticide concentrations (NRC, 1976).

Suspended solids ranged from below the detection limit of 10 mg/l to 265 mg/l during the August 19 hurricane. The next highest value was 226 mg/l after the June 11 thunderstorm.

Total volatile solids (TVS)is the residue after ignition at 550 °C and consists of primarily organic matter. It also includes $MgCO_3$ some alkalis and chlorides that also decompose or volatilize. TVS can be used as an indirect measure of the oxygen demanding fraction of water. Total volatile solids ranged from below the detection limit of 10 mg/l to 273 mg/l.

Turbidity in water is caused by the presence of suspended matter such as clay, silt, nonliving organic particulates, plankton, and other microscopic organisms. Turbidity measures the light scattering and absorbing property of water. The clarity of water affects the aesthetics of drinking water and is a general indicator of the condition and productivity of the system.

The drinking water standard is 5 NTU for source water and 1 NTU for finished water. Turbidity during the storms ranged from 0.2 to 14 NTU. During routine sampling, turbidity levels as high as 95 NTU have been measured.

Nutrients

The high levels of phosphorus and nitrogen typically observed in stormwater runoff can cause algal blooms when the elevated tributary nutrient loads are carried into the reservoir. The nutrients in stormwater runoff are in the soluble form readily taken up by algae (Schueler, 1987). MWRA water users have complained of taste and odor problems that has been related to algal growth in the reservoir. These problems are usually associated with increases in Synura, a golden-brown alga. Synura can cause serious taste and odor problems when present at very low concentrations. Control of nutrient loading that promotes growth of this alga is very important to this system. Taste and odor problems do not constitute a risk to health for consumers, but are aesthetic problems and cause consumers to purchase bottled water or invest in expensive home filtration systems.

Nutrient export is generally greater as the impervious area increases in the watershed, unless there are land uses with a high fertilizer application rate, as in golf courses, cemeteries, and other intensively landscaped areas (Schueler, 1987).

Phosphorus is present in natural waters as phosphate (PO_4^-), its highest oxidized form. It may occur in dissolved, colloidal, or particulate states. Phosphorus can occur in soluble and insoluble inorganic compounds, including orthophosphate, polyphosphate, and metaphosphates. Organic phosphate occurs in aquatic organisms and detritus. It is essential to a wide variety of biological and chemical processes. All living protoplasm contains about two percent phosphorus on a dry weight basis. Phosphorus can be the element in short supply that limits the growth of photosynthetic aquatic plants (Snoeyink and Jenkins, 1980).

Phosphorus that enters via the tributaries to Wachusett Reservoir will reach the reservoir as part of the fluid mass, as bed load sediments carried downstream, or as floating organic materials. Phosphorus can enter the surface water from several different sources. Agricultural, forest, and residential areas contribute varying amounts in storm runoff. Organic phosphate sources include runoff, septic system leachate, and biological processes. The human body excretes about one pound per year of phosphorus expressed as total phosphorus. Phosphorus detergents and other domestic sources raise each persons contribution to 3.5 pounds/year (USEPA, 1986b). When septic systems are not operating properly, a disproportionate amount of this phosphorus may reach the stream. Organic phosphates are also formed from orthophosphates by stream biota.

To protect waterbodies from noxious weed and algae growth, total phosphorus should not exceed 0.050 mg/l in a stream at the point where it enters the reservoir, or 0.025 mg/l within the reservoir (USEPA, 1986b). The range of total phosphorus in the stormwater sampling at Gates Brook was 0.005 to 0.86 mg/l. The mean concentration from each storm exceeded the 0.05 mg/l standard in all but three storms. The level of phosphorus in the four dry weather composites during the study ranged from 0.016 to 0.041 mg/l. During 1987-1988 study (Tighe & Bond, 1989), the mean phosphorus concentration at Gates Brook was 0.056 mg/l.

The choice of the digestion method for the total phosphorus analyses was affected by the solids in the samples. The analytical method for phosphorus is a two-step procedure. The first step is digestion, where the phosphorus is released from organic matter and hydrolyzed to the orthophosphate form. In the second colorimetric step, the orthophosphate is complexed with ammonium molybdate to form a blue-colored solution. There are three digestion methods in Standard Methods Section 424C (APHA, 1989): perchloric acid digestion, sulfuric acid-nitric acid digestion, and persulfate digestion. Perchloric acid digestion was not considered because it is explosive and requires a special hood in the laboratory. In the sulfuric acid-nitric acid method, the samples are acidified and heated at high temperatures in an automatic digestion block before colorimetric analysis. In the persulfate method, the samples are acidified, persulfate added, and heated on a hot plate. Sulfuric acid-nitric acid digestion is more rigorous than persulfate digestion, but there is more variability in the results as shown in **Figure 3-1** Persulfate digestion was used because it is presumed to give a better representation of naturally occurring processes. This method was also recommended for routine analysis in the National Urban Runoff Program (NURP) studies (USEPA, 1976).

Nitrogen compounds are present in natural waters in several forms. They are found in cellular components, particulate matter, soluble organic substances, and inorganic ions. The most important compounds, in order of decreasing oxidation state, are nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_3^-), and organic nitrogen. Along with molecular nitrogen gas, these compounds are part of the nitrogen cycle. Many of the reactions of the nitrogen cycle are linked to the metabolic activity of microorganisms. The microorganisms do not actually perform the chemical reactions in the nitrogen cycle, but catalyze the reactions for energy and biosynthesis (Snoeyink and Jenkins, 1980). The redox reactions are nitrification, the oxidation of ammonium ion to nitrite; nitrate reduction, the reduction of nitrate to nitrite, and subsequently to ammonium ion; denitrification, the reduction of nitrate to gaseous nitrogen, and nitrogen fixation, the reduction of gaseous nitrogen to ammonium ion.

Nitrogen sources in the environment are septic tanks, fertilizer and animal wastes, atmospheric fallout, automobile discharges, and mineralization of soil organic matter (NAS, 1972).

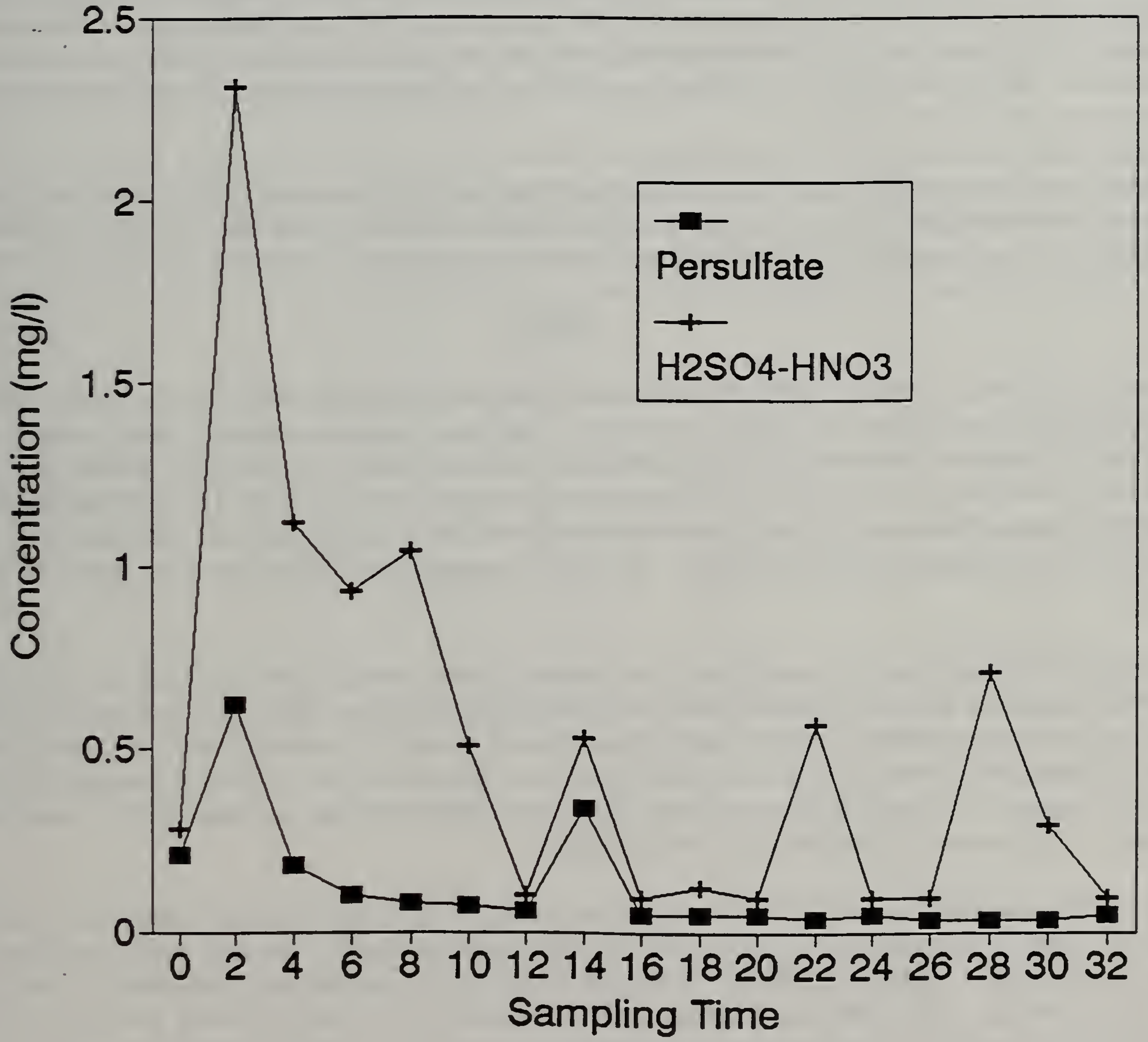
Organic nitrogen (proteins, nucleic acids, and urea) are found in soil organic matter and plant and animal protein. When these compounds decompose, the produce ammonia-nitrogen. In the laboratory, organic nitrogen and ammonia are analyzed together as total Kjeldahl-nitrogen (TKN). Organic nitrogen may be determined by subtracting the ammonia from TKN in each sample. Organic nitrogen concentrations range from a few hundred micrograms per liter in some lakes to 20 mg/l in wastewater (APHA, 1985). TKN was not measured in the earlier study, but during the sampled storms, TKN ranged from 0.06 to 3.14 mg/l (mean of 0.79 mg/l). Organic nitrogen ranged from 0.12 to 1.59 mg/l (mean of 0.62 mg/l).

Ammonia (NH_3^-) is released during the decomposition of organic matter and can also be formed by the reduction of nitrate. ammonia is bound to soil particles and clay and is not usually leached form soil. Ammonia exerts a high oxygen demand, and is toxic to aquatic organisms. The toxicity is affected by dissolved oxygen concentration, temperature, pH, previous acclimation to ammonia, intermittent exposures, carbon dioxide concentrations, salinity, and the presence of other toxicants (USEPA, 1986b). The mean ammonia concentrations during the 1987-1988 study was 0.06 mg/l. During the stormwater study, the ammonia levels ranged from below the limit of detection (0.02 mg/l) to 0.08 mg/l.

FIGURE 3-1

GATES BROOK STORMWATER STUDY

Phosphorus Digestion Method Comparison



Nitrite (NO_2^-) is formed by oxidation of ammonia and reduction of nitrate by soil and water organisms, in sewage, and in the digestive tract. Nitrite is an intermediate step towards the complete oxidation of the ammonium ion to nitrate.

Nitrate (NO_3^-) is the most thermodynamically stable form of combined nitrogen in oxygenated water. The nitrate ion is formed by the complete oxidation of ammonium ions. Since there is a tendency for all nitrogenous material to be converted to nitrate in natural water, all sources of combined nitrogen should be considered potential sources of nitrate.

When nitrate is reduced to nitrite in the digestive tracts of infants, the oxygen carrying capacity of the blood is reduced, resulting in methemoglobinemia, or "blue baby." Gastric pH greater than 4 is conductive to the growth of nitrate-reducing bacteria, and infants are more likely to have alkaline stomachs. Nitrite also reacts with secondary amines or amides to form N-nitroso compounds, which are carcinogens (NRC, 1977).

Federal and state standards set the maximum nitrate level for water supplies at 10 mg/l to protect against methemoglobinemia. The mean value during the earlier study was 1.61 mg/l. The range during wet weather was 0.25 to 2.0 mg/l, well below the standard.

Metals

The concentration of metals in stormwater runoff is important because of the human health concerns and potential toxic effects on aquatic organisms. The runoff samples collected during seven storms and six dry weather, snow melt, or other conditions were analyzed for aluminum, arsenic, cadmium, calcium, chromium, copper, iron, lead, manganese, mercury, nickel, and zinc. The sampling for metals was discontinued because the levels were often below the limits of detection and the laboratory could only handle a limited number of samples. Stormwater monitoring data for metals are listed in **Table 3-5**.

Most of the metals found in runoff are from "leakage" from developed areas (Schueler, 1987). The primary source of most pollutants is from the atmosphere (Schueler, 1987). Up to 90 percent of the wet and dry precipitation from the atmosphere makes its way to receiving waters (Oberts, 1985). Metal flashing and other roofing materials, downspouts, galvanized pipe, and metal plating are sources of trace metals. As these surfaces corrode, flake, and dissolve, metals are deposited in stormwater runoff. This process is accelerated up by acid rain.

There are several factors that should be considered when assessing the effects of metals in stormwater runoff. First, a large portion of the metals are attached to sediment, and may rapidly settle out of the water column (Schueler, 1987). Therefore, they are not immediately available for biological uptake (OWML, 1983; Galvin and Moore, 1982). Second, runoff events last for shorter periods of time than the exposure time in aquatic bioassays (24 hours to a week for chronic toxicity testing). Third, the runoff from developed areas is mixed with other sources. However, the more soluble metals such as copper and zinc are likely to be toxic in some situations (JTC, 1982).

In order to determine the potential for any metal-related instream toxicity to fish and other aquatic organisms in Gates Brook, the data were compared to the USEPA water quality criteria. The chronic aquatic life criteria is protective for exposures based on the average concentration over a four-day period not exceeding the criteria more than once every three years on the average. The acute criteria is based on the one-hour average concentration not exceeding the criteria more than once every three years on the average. The three-year period is the USEPA's best scientific judgement of the average amount of time it will take an unstressed system to recover from an event when the criteria were exceeded. Since the toxicity of several metals varies with hardness, the criteria were calculated using a mean stormwater hardness of 50 mg/l. The criterion for each metal is also noted in **Table 3-5**. The detection limit for cadmium and lead is greater than the criteria, and the potential for any instream metal toxicity could not be assessed. The freshwater criterion for mercury is very conservative because it is bioconcentrated in the food chain (USEPA, 1985f). In some instances, aquatic organisms are more sensitive to toxic metals, and the aquatic life criteria are lower that the drinking water standard. An additional measure of the relative potential toxicity of instream metals is the Toxic Unit (TU). Toxic Units are the ratio of the concentration of the chemical in question and the chronic criterion of the chemical.

A variety of metals were found in the urban runoff sampled collected during the National Urban Runoff Program (NURP) studies. With the exceptions of lead, cadmium, copper, and zinc, most of the trace metals were found in only a few of the samples and in small amounts well below drinking water and aquatic life standards. Of the twelve metals tested in the Gates Brook stormwater, six exceeded the drinking water standards at least once, and eight exceeded the aquatic life criteria at least once.

TABLE 3 - 5

GATES BROOK STORMWATER STUDY

Metals Data and Water Quality Criteria and Drinking Water Standards (mg/l)

Date		Fe	Mn	Ca	Al	Cu	Zn	Pb	Cr^{+6}/Cr^{+3}	Cd	Ni	As	Hg
Drinking Water Std:		0.3^1	0.05^1		0.2^{1,2,3}	1.3	5.0^1	0.015	0.1	0.005	0.1	0.05	0.002
Chronic WQ Criterion:		1.0^3	--		0.087^4	0.0065	0.059	0.0013	0.011/0.117	0.00066	0.088	0.190	0.000012
Acute WQ Criterion:		--	--		0.750^4	0.0092	0.065	0.034	0.016/0.984	0.0018	0.789	0.360	0.0024
10/23/90	Max	0.15	0.04	23	0.056	0.007	0.08	0.001	0.001	0.003	0.003	0.003	0.0002
	Min	0.08	0.02	20	<0.05	0.002	0.02	<0.001	<0.001	<0.001	0.002	0.001	<0.0002
	Avg	0.12	0.03	22	0.053	0.004	0.04	0.001	0.001	0.002	0.002	0.002	0.0002
12/04/90	Max	3.5	1.3	24	1.8	0.01	0.2	0.06	0.063	0.009	0.014	0.014	0.0004
	Min	<0.05	0.015	5	<0.05	<0.002	0.03	<0.002	<0.002	<0.002	0.003	<0.001	<0.0002
	Avg	1.31	0.30	13	0.72	0.004	0.072	0.013	0.011	0.004	0.007	0.005	0.0002
01/16/91	Max	3.4	0.4	29	1.8	0.041	0.12	0.023	0.008	0.005	0.13	0.01	0.0003
	Min	0.16	0.08	15	0.1	<0.002	0.025	<0.002	<0.001	<0.001	<0.002	0.001	<0.0002
	Avg	1.10	0.17	21	0.59	0.010	0.070	0.007	0.002	0.002	0.014	0.003	0.0002
02/07/91	Max	2.70	0.32	16	1.60	0.007	0.061	0.019	0.002	0.003	0.003	0.007	0.0094
	Min	0.18	0.06	8	0.06	0.003	0.011	<0.002	<0.001	<0.001	<0.002	0.002	<0.0002
	Avg	0.81	0.14	13	0.45	0.005	0.027	0.005	0.001	0.001	0.002	0.003	0.0016
04/30/91	Max	21	2.8	18	4.9	0.029	0.18	0.085	0.011	0.002	0.03	0.004	0.0002
	Min	0.05	<0.01	5	0.07	<0.002	<0.005	<0.002	<0.002	<0.002	<0.002	<0.001	<0.0002
	Avg	2.29	0.32	10	0.73	0.006	0.040	0.010	0.003	0.002	0.005	0.002	0.0002
05/30/91	Max	0.52	0.23	29	0.7	0.03	0.06	0.012	0.002	0.002	0.003	0.009	0.0002
	Min	0.07	<0.03	13	<0.05	<0.03	<0.005	<0.002	<0.002	<0.002	<0.002	<0.001	<0.0002
	Avg	0.22	0.06	21	0.18	0.03	0.022	0.004	0.002	0.002	0.002	0.004	0.0002
09/20/91	Max	0.64	2.2	16	0.17	0.26	0.02	0.015	0.001	0.002	0.002	0.006	0.0002
	Min	0.06	0.14	15	0.05	0.025	0.01	0.002	<0.001	<0.002	<0.002	0.004	<0.0002
	Avg	0.35	1.17	16	0.11	0.14	0.02	0.009	0.001	0.002	0.002	0.005	0.0002
Summary	Max	21	2.8	29	4.9	0.26	0.2	0.085	0.063	0.009	0.13	0.014	0.0094
	Min	0.05	<0.01	5	0.07	<0.002	<0.005	<0.001	<0.001	<0.001	<0.002	<0.001	<0.0002
	Avg	0.88	0.31	17	0.40	0.028	0.041	0.007	0.003	0.002	0.005	0.003	0.0004

Criterion calculated at hardness of 50 mg/l as $CaCO_3$

(t3-xx)

Notes:

[1] EPA secondary standard and MA guideline

[2] Maximum recommended concentration

[3] Range of 0.05 to 0.2 mg/l

[4] pH dependent

The primary drinking water MCL for aluminum is one mg/l. At pH 6.5 to 9.0, the chronic aquatic life criteria is 0.087 mg/l, and the acute criteria is 0.75 mg/l. In all but one storm, the chronic water quality criterion was exceeded by the mean storm concentrations. The peak storm concentration exceeded the acute criteria of 0.75 mg/l in more than half the sampled storms. The stormwater concentrations ranged from 0.07 to 4.9 mg/l.

Arsenic compounds are widely distributed at low concentrations in U.S. waters (Durum, 1974; USEPA, 1985a). The primary drinking water MCL for arsenic is 0.05 mg/l, which protects against skin and lung cancer and kidney damage. The aquatic life criteria is 0.190 mg/l for chronic exposure and 0.36 mg/l for acute exposure. The stormwater concentrations ranged from 0.001 to 0.014 mg/l and were all well below the drinking water and aquatic life criteria.

In pure, fresh water, cadmium sometimes occurs at concentrations of less than 0.01 µg/l, but where streams have been impacted by development, the concentration can be several µg/l or greater (USEPA, 1985b). The primary MCL for cadmium was set at 0.010 mg/l. The aquatic life criteria are 0.0018 mg/l (1.8 µg/l) for acute exposures and 0.00066 mg/l (0.66 µg/l) for chronic exposures. The storm samples met the primary MCL for cadmium. The chronic aquatic life criteria is below the limits of detection for the laboratory analysis and the mean concentration for each storm ranged from 0.001 to 0.004 mg/l.

There are no drinking water or water quality criteria for calcium. The calcium concentrations ranged from 5 to 29 mg/l.

Significant quantities of chromium (III) or chromium (VI) or both, exist in natural water and are converted back and forth under natural conditions (USEPA,1985c). Because the chemical and toxic properties are different for each oxidation state and are not additive, separate criteria have been developed for Cr (VI) and Cr (III). To protect against liver, kidney and lung diseases, the primary MCL for chromium (VI) is 0.05 mg/l. The peak concentration during one storm exceeded the drinking water criterion. For chronic exposure, the aquatic life criterion is 0.011 mg/l, and for acute exposure, the criterion is 0.016 mg/l. The mean stormwater concentration during one storm was equal to the chronic exposure level for Cr (VI). The aquatic life criteria for Cr (III) adjusted for hardness is 0.117 mg/l for chronic and 0.984 mg/l for acute exposures. The samples were always below this level, ranging from <0.001 to 0.063 mg/l.

Copper is a minor nutrient for both plants and animals at low concentrations but is toxic at slightly higher levels (USEPA, 1985). Concentrations of one to ten µg/l are usual in unpolluted surface waters. The drinking water primary MCL is 1.3 mg/l. Copper can cause anemia, digestive disturbances, and liver and kidney damage. The secondary MCL, based on controlling undesirable tastes and odors, is 1.0 mg/l. The samples collected during the study always met these standards. Aquatic organisms are very sensitive to copper. The toxicity of copper decreases as hardness increases, and at Gates Brook hardness concentrations, the chronic aquatic life criterion is 0.0065 mg/l (6.5 µg/l) and the acute criterion is 0.0092 mg/l (9.2 µg/l). The concentrations ranged from <0.002 to 0.26 mg/l and the chronic and/or acute criteria was exceeded by the mean value in five of the seven storms.

Concentrations of iron above the secondary MCL set at 0.3 mg/l cause taste problems and laundry stains. The maximum concentration allowed to protect aquatic life is 1.0 mg/l. The stormwater concentrations ranged from 0.05 to 21 mg.l and both of these criteria were regularly exceeded during the storms. The mean iron concentration from all storms was 0.88 mg/l, in part because the peaks were often an order of magnitude greater than the secondary MCL.

The primary MCL for lead is 0.05 mg/l to prevent brain and nerve damage, especially in children (Stewart et al, 1989). This level was exceeded by the peak concentrations in two storms. The toxicity of lead decreases as hardness increases (USEPA, 1985). At the Gates Brook hardness, the chronic water quality criteria is 0.0013 mg/l (1.3 μg/l) and the acute level is 0.034 mg/l (34 μg/l). The level in the stormwater ranged from below detection to 0.085 mg/l. The chronic level, below the limit of detection, was exceeded in all but one storm. The acute water quality criterion was exceeded twice.

Manganese is not found in natural conditions as a metal, but rather as a salt or mineral, and is often associated with iron compounds. Permanganates are very strong oxidizing agents of organic materials. The secondary drinking water standard was set at 0.05 mg/l to reduce taste complaints and brown laundry stains. Low iron concentrations may intensify the adverse effects of manganese (USEPA, 1986b). Although manganese ions are rarely found in surface waters above 1.0 mg/l (USEPA, 1986b), the peak storm concentrations were equal or twice as high on three occasions. The mean storm concentrations exceeded the drinking water standard during most storms. The mean manganese concentration was 0.31 mg/l.

Mercury is one of the most toxic of the heavy metals, and can be a serious pollutant in surface waters (USEPA, 1985f). Methylmercury is the most chronically toxic mercury compound, and the criterion assumes that all the mercury is methylmercury. The health effects of mercury are brain and nerve damage, birth defects, and skin rash. The drinking water primary standard is 0.002 mg/l. Although most of the samples were at or below the limit of detection, during one storm the peak concentration was four times higher than this standard. The chronic aquatic life criteria is 0.000012 mg/l (0.012 μg/l), below the limit of detection, and the acute level is 0.0024 mg/l (2.4 μg/l). The average mercury concentration exceed the criterion by 33 toxic units. The concentrations ranged from below detection to 0.0094 mg/l (9.4 μg/l).

Another common metal in surface water is nickel. Under natural conditions, the divalent cation is predominant and is considered most toxic (USEPA, 1986a). Alkalinity, hardness, pH, and temperature affect the toxicity and availability of nickel. The USEPA has proposed a primary MCL of 0.1 mg/l. Although nickel concentrations were usually at or below the limit of detection (0.002 mg/l) the proposed standard was surpassed during one storm. The aquatic life criteria are 0.088 mg/l for chronic exposure, and 0.789 mg/l for acute exposures. The chronic criteria was exceeded once.

The concentration of zinc in water, like lead and cadmium, can be correlated with runoff from developed areas (Durum, 1974). Concentrations of 30 mg/l give water a strong astringent taste and murky appearance. Zinc may be picked up in the distribution system in soft water areas like Boston (NRC, 1977). The secondary standard for zinc is based on the threshold at 5 mg/l for a metallic taste. The chronic water quality criterion for zinc is 0.059 mg/l (59 μg/l) and the acute criterion is 0.065 mg/l (65 μg/l) (USEPA, 1980). The acute standard was exceeded by peak concentrations during four storms, and the chronic criterion was exceeded during two storms. All samples met the drinking water criterion. The concentration of zinc in the stormwater samples ranged from below the detection limit to 0.2 mg/l.

Bacteria

Samples were collected and analyzed for fecal coliform bacteria during 9 of 24 storms, and once during dry weather sampling. **Table 3-6** presents a summary of maximum and minimum bacteria levels from each storm sampled. Means and standard deviation were calculated. However, due to the limited data, these statistics are include only to illustrate the large variability in the data collected during this study. They are not considered as an accurate statistical representation of bacteria conditions in Gates Brook.

TABLE 3 - 6

GATES BROOK STORMWATER STUDY

Summary of Fecal Coliform Analysis
(colonies per 100 ml)

Dry Weather Sampling

Date	No. Samples	Maximum	Minimum	Mean	S.D.
10/15/90	5	400	180	276	81.73

Wet Weather Sampling

Date	No. Samples	Maximum	Minimum	Mean	S.D.
10/23/90	7	180	120	146	25.73
01/16/91	13	240	36	93	68.70
02/07/91	3	720	130	357	317.86
04/30/91	12	4100	110	1281	1285.77
06/05/91	1	145	--	--	--
06/12/91	9	12800	332	6704	4213.95
06/19/91	9	9600	80	3778	3455.00
07/23/91	7	30000	3000	9143	9352.87
09/19/91	12	18500	1800	8952	5602.28
09/25/91	7	18500	8500	12800	3871.69

MDC Annual Monitoring Reports

Date	No. Samples	Maximum	Minimum	Mean	S.D.
1991	22	18500	4	907	3930.64
1990	21	800	6	111	179.59
1989	21	210	0	42	53.69

(bacteria)

3.7 Problems Encountered During Sampling

The sampling program associated with this type of study is different from the sampling that has typically been done by MDC-EQS staff. The program should be an integral part of the scoping and design of the study. The sampling program of this study evolved during the actual study and, therefore, some inherent problems and differences in the data collected were encountered.

The window of opportunity for sampling was limited to Monday through Thursday due to laboratory constraints associated with bacteria analysis. As discussed previously, three antecedent dry days were established as a criteria for this study which eliminated some storms that began during the week.

The Worcester NOAA station forecasters were very helpful and provided detailed weather forecasts for the study. However, the distance between the sampling station and the Worcester Airport sometimes was too great to record accurate rainfall; especially for summer showers. The USGS loaned the study a rain gage, byt the winding mechanism was unreliable. The mechanism had to be replaced with a quartz movement which did not occur until late in the study.

The inability to utilize the liquid level actuator to trigger the sampler reduced the amount of data obtained. The limitation of sampling to times that were predicted by the NOAA caused samples to be taken of only portions of or totally missing the storm events. Sampling of the events that were of shorter durations or moved at speeds differing from those projected by the NOAA were not properly represented by the actual runoff characteristics.

Reliable measurements of large storm flows (in excess of 75 cfs) were not collected due to the hydraulic design of the sampling station. On several occasions the storm flow exceeded the capacity of the gaging mechanism and the brook breached the system. The MDC installed a 12 inch diameter relief culvert to minimize the damage from breaching, but this affected the flow measurements of larger storms.

The flow meter probe was placed so that it was vulnerable to rocks and debris that were being carried in the storm flow. The probe was held in place by metal clips bolted into the concrete culvert. Debris, (rocks, tires and logs) passing through the culvert struck the vane of the probe. On one occasion, high flows ripped the probe from the fasteners, and repair of the probe took several months. Therefore, flow data were not collected from March 3 to May 1, 1991. A grate was installed to protect the probe, but was abandoned because measurement of the flow was disrupted. The strainer for the ISCO sampler also broke away during another storm.

During the initial time of the study, storm duration exceeded the sampling equipment's capacity (ie, the number of bottles in the ISCO bases), so the sampling protocol was adjusted as described in Section 3.4. This reduced the accuracy of the estimation of the "first flush", but more information was obtained to estimate total loading.

Due to the localized nature of some of the events, good communication between personnel during storms did not occur. A communication system is essential to minimize repeated activities, and to inform others of problems that may arise at the sampling site.

The choice of the digestion method for the total phosphorus analyses was affected by the solids in the samples. Due to the sediment in the samples, the phosphorus that had combined with organic matter was digested and oxidized first. Persulfate digestion was used because it appeared to give a more accurate representation of naturally occurring processes.

4.0 MODELLING

4.1 Model Selection

Analysis of the impact of stormwater on a receiving water is complex. In dry weather studies, it is reasonable to assume steady state conditions for both the waste source and the receiving water. A complete analysis of a situation can be developed with limited pollutant concentration data and minimal amount of flow quantity data. In stormwater studies, however, pollutant concentrations and flow quantities, in both the pollutant source and the receiving water, vary with time. Pollutant concentrations, and runoff and receiving water volumes can vary by several orders of magnitude in a single storm. Increased sample collection can help to characterize the stormwater, but it is rarely possible to collect enough samples to accurately quantify pollutant loadings from stormwater. Even if resources are available to collect and analyze an adequate number of samples, the evaluation of all the data is very difficult. In order to evaluate effects of stormwater, it is almost always necessary to use a computer simulation model.

The overall objective of stormwater modelling is to make decisions about methods to mitigate stormwater pollution and/or flooding. Traditionally, there are three general classes of models which can be used to evaluate stormwater effects:

> Planning models are used for an overall assessment of stormwater problems. They are generally used as for a "first-cut" analysis to initially quantify the problem, and to investigate general classes of abatement options. Data requirements are minimal, and period of simulation is generally long (months or years).
>
> Design models are oriented toward detailed simulation of a single storm event (a design storm). Design models have extensive data requirements, and generally are run for a short period (a single storm, typically several hours).
>
> Operational models are used to produce actual control decisions during a storm event. The model is used to predict system responses, and then various control options may be employed (e.g. in system storage, diversions, etc.) (Huber and Heaney).

Initially, the MDC and DEP intended to use the Stormwater Management Model (SWMM) for analysis of the Gates Brook subwatershed. SWMM is an excellent stormwater model which can make very detailed water quality predictions. However, it has a large data input requirement, and requires significant staff time to get the model running on the user's computer system. Another factor for future considerations about using SWMM is the cost of the model. The version of SWMM which was to be used in this study costs approximately $2000.

MDC and DEP/OWM decided to use the P8 Urban Catchment Model (IEP, 1990; Walker, 1990) to analyze stormwater data collected in this study. P8 stands for Program for Predicting Polluting Particle Passage Thru Pits, Ponds, and Puddles. P8 is a planning level model. Review of the data base established by the sampling component of this study indicated that a planning level model would be more appropriate than a design level model. Other factors which where considered included the fact that P8 is developed for use on a personal computer, and is reasonably user-friendly. The model can be calibrated to site-specific conditions fairly easily, and can be used to develop preliminary recommendations for design of treatment alternatives. P8 is capable of modelling most of the parameters identified as pollution problems related to stormwater in the Gates Brook subwatershed.

4.2 P8 Model Description

The P8 Model was developed for the Narragansett Bay Project in Providence, Rhode Island to predict the generation and transport rates of pollutants associated with stormwater runoff in urbanized areas. Specific concerns in the Rhode Island study focussed on the impact of residential and commercial development to the environment (IEP, 1990).

Calibration of the P8 model to site-specific data is accomplished by adjustment of coefficients of specific components (ie. precipitation volume and NURP (National Urban Runoff Program) median event-mean runoff concentrations). The stormwater can be routed through treatment devices, including detention ponds, infiltration basins, flow splitters, swales, and buffers, and pollutant removal by each of the BMP's can be predicted.

4.3 Model Input

The information required for the P8 model includes site-specific watershed data, rainfall data, evapotranspiration and runoff parameters, and treatment device data. The input information was collected from a variety of sources. Watershed data were taken from field investigations and combined with information from the Massachusetts Geographic Information System (MASSGIS) database. Specific characteristics include drainage area, land use type, impervious area, soil types, and slopes.

Land use data were initially provided in 15 categories, as described in Section 2.4. This information was then reduced to three aggregate land use types--residential, commercial, and open/agricultural. Land uses in each aggregate group are considered to have similar runoff characteristics for modelling purposes. **Figure 4-1** shows the distribution of the residential, commercial, and open/agricultural land uses over the Gates Brook study area. Soil types and curve numbers were determined based on the land use designations and field experience.

Table 4-1 shows watershed characteristics as input for a model run. This display of the input data is part of the programming within the model.

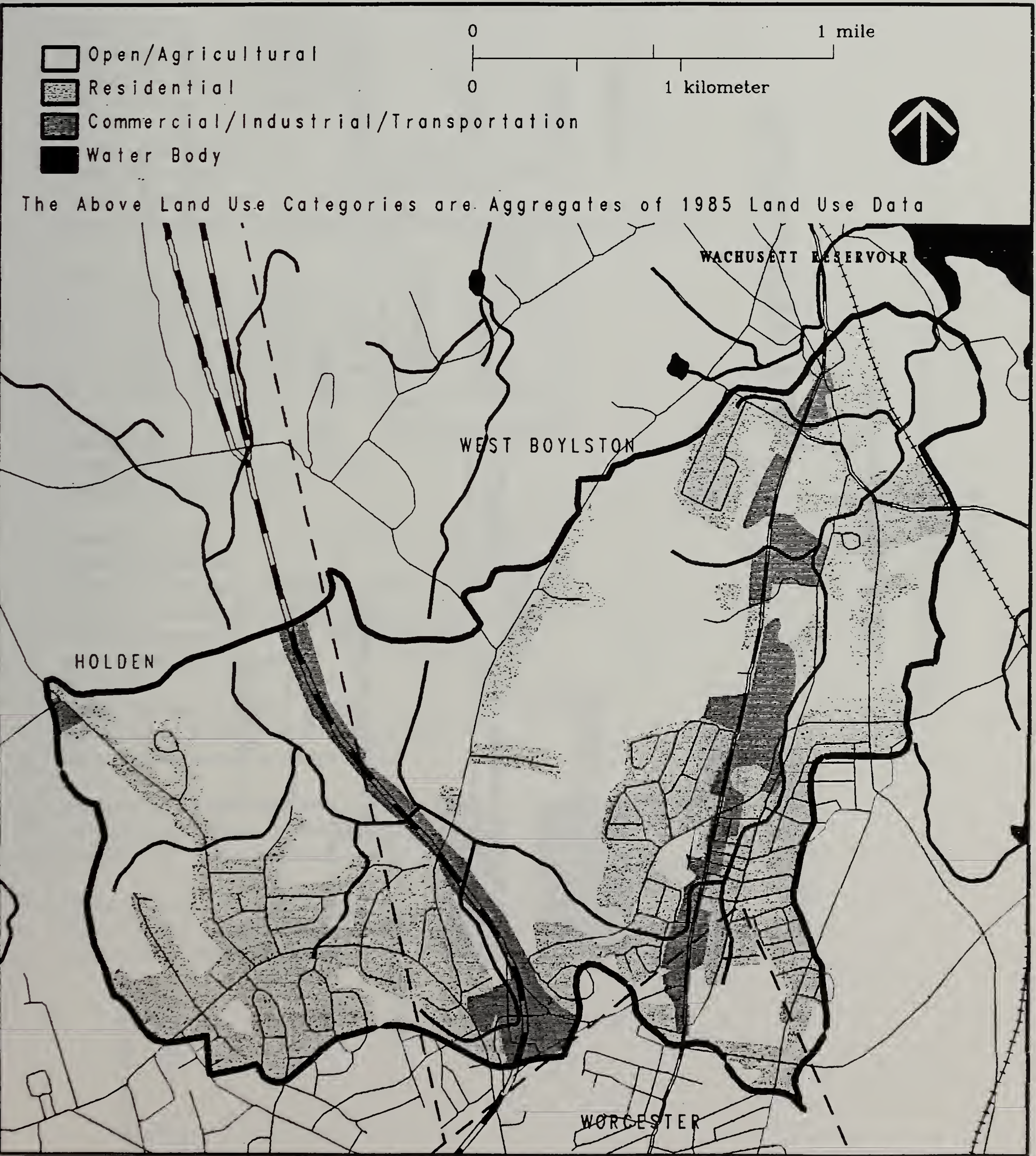
Precipitation and temperature data were taken from the National Oceanic and Atmospheric Administration (NOAA) database. A NOAA station located at the Worcester Airport provided rainfall data in hourly increments. This station is located approximately seven miles south of the Gates Brook subwatershed. Air temperature data were taken from the NOAA-Providence Airport station, located approximately 50 miles from the study area. Temperature data were available as monthly mean temperatures.

The initial particle characteristics and water quality component concentrations in runoff are based on data measured under the NURP study (Athayde et al., 1983). The model calculates particle concentrations in runoff using empirical equations, similar to those used in SWMM. The equations are based on pollutant buildup on the land, and direct runoff concentrations. A schematic of the mass balance system of the P8 Model for the Gates Brook subwatershed is shown in **Figure 4-2**. This schematic does not depict any treatment device.

Stormwater treatment device data are specific to the particular device being used or reviewed. The characteristics include location, storage capacity, inflow/outflow rates, flow directions, and material types.

Figure 4-1

GATES BROOK SUBWATERSHED: LAND USES

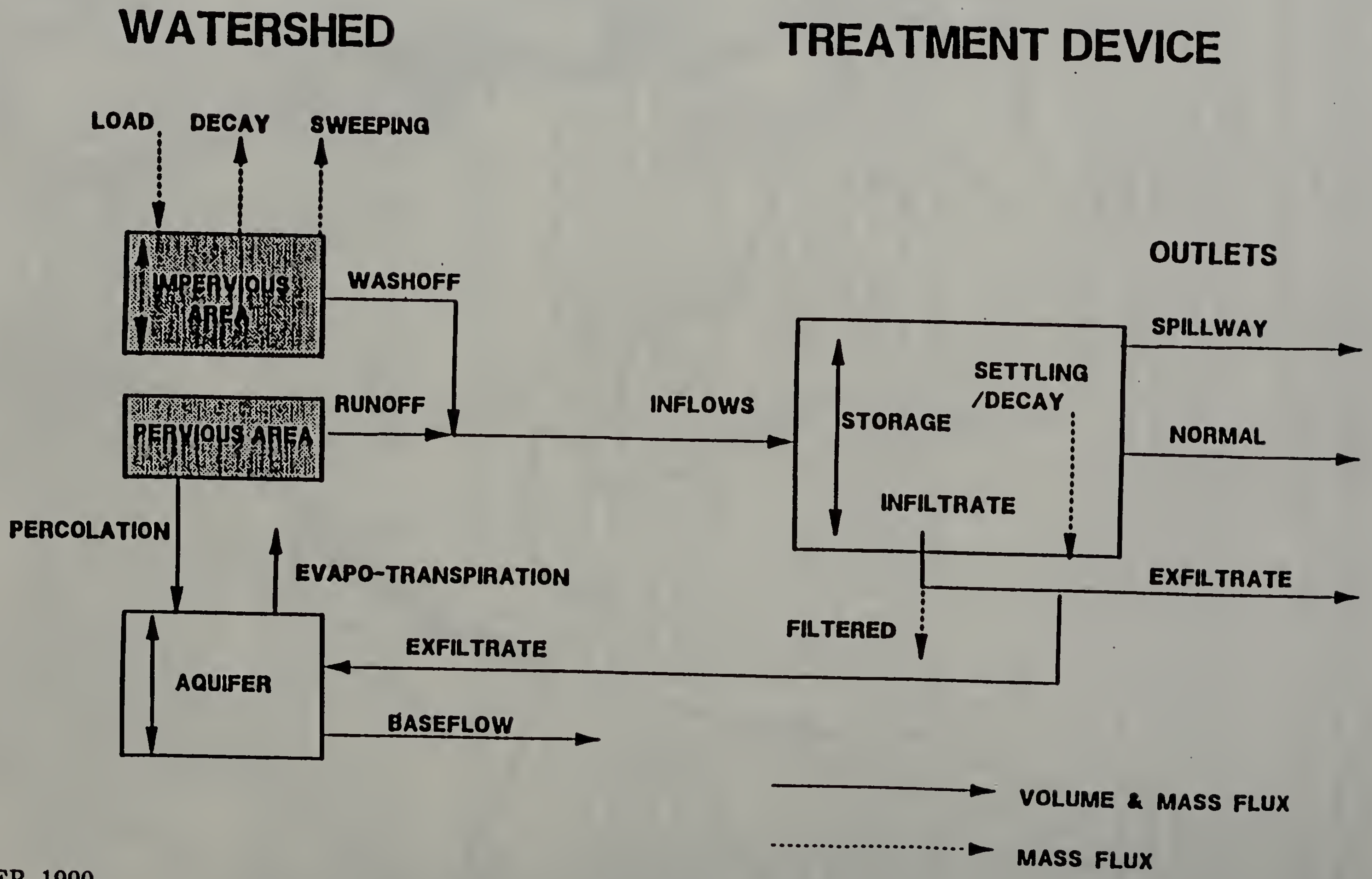


The Above Land Use Categories are Aggregates of 1985 Land Use Data

FIGURE 4 - 2

GATES BROOK STORMWATER STUDY

P8 Mass-Balance Schematic



*Source: IEP, 1990

TABLE 4-1, page 1
Input for the P-8 Model

```
Case Data File  =  FINAL.CAS
Storm Data File =  worc8891.stm
Particle File   =  NURP50.PAR
Air Temp File   =  prov6988.tmp

precipitation volume factor          =  1.000
storm duration factor                =  1.000
number of passes through storm file  =      1
storm dates{yymmdd}: start = 901201, keep = 910115, stop = 910620

case notes:
        Gates Brook simulation
        West Boylston, MA
        Calibration to observed flows
        Calibration of runoff parameters
        Drainage Area  =  2028 acres

watershed              =  1 gates
surface runoff device  =  1 runoff
percolation device     =  2

watershed area                    acres      =  2028.000
impervious fraction                          =      .250
impervious depression storage     inches     =      .020
scs curve number (pervious portion)          =    30.000
sweeping frequency                times/week =      .000
water quality load factor           -        =     1.000

device 1 = runoff, type = 5 pipe
time of concentration  =      7.000 hours
normal outlet routed to device 3 total

device 2 = baseflow, type  =  7 aquifer
time of concentration  =  700.000 hours
normal outlet routed to device 3 total

device 3 = total, type  =  5 pipe
time of concentration  =     .000 hours
normal outlet routed to device  0  OUT
```

TABLE 4-1, page 2
Input for the P-8 Model

PARTICLE CLASS INFORMATION:

particle class = 1 PO%

filtration efficiency % = 90.000
particle settling velocity ft/hr = .000
first order decay rate 1/day = .000
second order decay rate 1/day-ppm = .00000
impervious runoff concentration ppm = 1.0000
pervious runoff concentration ppm = 1.0000
pervious conc vs. runoff inten. exponent = .000
particle accumulation rate lbs/ac-day = .000
particle removal rate 1/day = .000
washoff co-efficient = .000
washoff exponent = .000
street sweeper efficiency %/pass = .000

particle class = 2 P10%

filtration efficiency % = 100.000
particle settling velocity ft/hr = .030
first order decay rate 1/day = .000
second order decay rate 1/day-ppm = .00000
impervious runoff concentration ppm = .0000
pervious runoff concentration ppm = 100.0000
pervious conc vs. runoff inten. exponent = 1.000
particle accumulation rate lbs/ac-day = 1.750
particle removal rate 1/day = .250
washoff co-efficient = 20.000
washoff exponent = 2.000
street sweeper efficiency %/pass = 4.000

particle class = 3 P30%

filtration efficiency % = 100.000
particle settling velocity ft/hr = .300
first order decay rate 1/day = .000
second order decay rate 1/day-ppm = .00000
impervious runoff concentration ppm = .0000
pervious runoff concentration ppm = 100.0000
pervious conc vs. runoff inten. exponent = 1.000
particle accumulation rate lbs/ac-day = 1.750
particle removal rate 1/day = .250
washoff co-efficient = 20.000
washoff exponent = 2.000
street sweeper efficiency %/pass = 8.000

TABLE 4-1, page 3
Input for the P-8 Model

particle class = 4 P50%

filtration efficiency % = 100.000
particle settling velocity ft/hr = 1.500
first order decay rate 1/day = .000
second order decay rate 1/day-ppm = .00000
impervious runoff concentration ppm = .0000
pervious runoff concentration ppm = 100.0000
pervious conc vs. runoff inten. exponent = 1.000
particle accumulation rate lbs/ac-day = 1.750
particle removal rate 1/day = .250
washoff co-efficient = 20.000
washoff exponent = 2.000
street sweeper efficiency %/pass = 12.000

particle class = 5 P80%

filtration efficiency % = 100.000
particle settling velocity ft/hr = 15.000
first order decay rate 1/day = .000
second order decay rate 1/day-ppm = .00000
impervious runoff concentration ppm = .0000
pervious runoff concentration ppm = 200.0000
pervious conc vs. runoff inten. exponent = 1.000
particle accumulation rate lbs/ac-day = 3.500
particle removal rate 1/day = .250
washoff co-efficient = 20.000
washoff exponent = 2.000
street sweeper efficiency %/pass = 16.000

TABLE 4-1, page 4
Input for P-8 Model

WATER QUALITY COMPONENTS

VARIABLE LABEL	1 tss	2 tp	3 tkn	4 cu	5 pb	6 zn	7 hc
PARTICLE FRACTION	**PARTICLE COMPOSITION (ppm)**						
1	0	99000	600000	13600	2000	64000	250000
2	1000000	3850	15000	340	180	1600	22500
4	1000000	3850	15000	340	180	1600	22500
4	1000000	3850	15000	340	180	1600	22500
5	1000000	0	0	0	180	0	22500
SCALE FACTOR	0.5	0.5	0.66	1.0	1.0	1.0	1.0
LEVEL	WATER QUALITY CRITERIA (ppm)						
A	5	0.025	2	2	0.02	5	0.1
B	10	0.05	1	0.0048	0.014	0.0362	0.5
C	20	0.1	0.5	0.02	0.15	0.38	1

TABLE 4-1, page 5

Input for the P-8 Model

```
WATER QUALITY COMPONENTS:

water quality component  =  1  tss
criteria (a,b,c) ppm = 5.000  10.000  20.000
particle frac.  contents (mg/kg)
     1               .00
     2         500000.00
     3         500000.00
     4         500000.00
     5         500000.00

water quality component  =  2  tp
criteria (a,b,c) ppm = .025  .050  .100
particle frac.  contents (mg/kg)
     1          49500.00
     2           1925.00
     3           1925.00
     4           1925.00
     5               .00

water quality component  =  3  tkn
criteria (a,b,c) ppm = 2.000  1.000  .500
particle frac.  contents (mg/kg)
     1         396000.00
     2           9900.00
     3           9900.00
     4           9900.00
     5               .00

water quality component  =  4  cu
criteria (a,b,c) ppm =  2.000  .005  .020
particle frac.  contents (mg/kg)
     1          13600.00
     2            340.00
     3            340.00
     4            340.00
     5               .00

water quality component  =  5  pb
criteria (a,b,c) ppm = .020  .014  .150
particle frac.  contents (mg/kg)
     1           2000.00
     2            180.00
     3            180.00
     4            180.00
     5            180.00

water quality component  =  6  zn
criteria (a,b,c) ppm = 5.000  .036  .380
particle frac.  contents (mg/kg)
     1          64000.00
     2           1600.00
     3           1600.00
     4           1600.00
     5               .00

water quality component  =  7  hc
criteria (a,b,c) ppm =  .100  .500  1.000
particle frac.  contents (mg/kg)
     1         250000.00
     2          22500.00
     3          22500.00
     4          22500.00
     5          22500.00


PROGRAM OPTIONS:

wet time step           hours  =   1.00
dry time step           hours  =   8.00
wet/dry lag             hours  =     2
wet/dry stability crit in/hr  =  .050
maximum continuity error %     =   2.00
```

TABLE 4-1, page 6
Input for the P-8 Model

WATER QUALITY CRITERIA

COMPONENT (ppm)	LEVEL A	LEVEL B	LEVEL C
Total Suspended	5	10	20
Total Phosphorus	0.025	0.05[d]	0.10[e]
Total Kjeldahl N	2.0	1.0	0.5
Total Copper	2.0[a]	0.0048[b]	0.02[c]
Total Lead	0.02[a]	0.0140[b]	0.15[c]
Total Zinc	5.0[a]	0.0362[b]	0.38[c]
Total Hydrocarbons	0.1	0.5	1.0

a - USEPA primary drinking water standard

b - RI standard, acute toxicity, fresh waters, hardness - 25 ppm

c - NURP threshold for aquatic life, intermittent exposure, soft waters (Athayede et al, 1983)

d - USEPA (1976) guideline for eutrophication in streams

e - USEPA (1976) guideline for streams entering lakes

Other criteria are arbitrary benchmarks (no standards or design criteria were established)

4.4 Description of Sampled Storm Events

The ranges of values for each parameter observed historically and during the wet weather sampling period from all storms are listed in **Table 4-2**. The complete data from all storms can be found in **Appendix B**. A total of twenty-four storms were sampled and for reasons specified in Chapter 3, the model was calibrated using six storm events. The following is a description of the sampled storms.

The January 16, 1991 storm event began as drizzle. Heavy rain did not begin until seven hours later, resulting in total rainfall of 0.57 inches. Seven inches of snow had fallen during two days the preceding week, followed by three dry days, leading to chlorides ranging from 190 to 520 mg/l. At the peak of the storm, total solids measured 1176 mg/l, total Kjeldahl-nitrogen concentration was 1.30 mg/l and total phosphorus was 0.29 mg/l. These values were twice the highest concentrations recorded during routine sampling (see **Table 4-2**), and this storm carried the second highest load of nutrients and solids to the reservoir. **Table 4-3** lists the nutrient loading and concentrations associated with each sampled storm event.

The largest storm event sampled (0.71 inches) occurred on February 7, 1991, beginning around midnight and continuing until 8:00 pm. There were five antecedent dry days. Sampling began after the peak in order to collect the tail of the storm flow. Conductivity, chlorides, suspended solids, and total volatile solids followed similar patterns of slowly rising concentration levels as rainfall decreased which may reflect basin characteristics. Suspended solids and total phosphorus concentrations were observed to decrease as the storm progressed, possibly due to dilution. Kjeldahl-nitrogen, turbidity, iron and magnesium varied in direct relation to the rainfall. This storm carried the largest solids load to the reservoir (**see Table 4-3**), but the highest concentration of total solids was 232 mg/l, far less than during the January storm. The maximum concentrations for suspended solids (78 mg/l) and phosphorus (0.27 mg/l) were similar to the earlier storm, but the mean values were much lower. This may be attributed to the fact that the storm sample did not represent the entire event.

The next storm, on May 30, occurred when there was a low base flow condition with full vegetative cover. During this storm 0.68 inches of rain fell over a period of four hours. Two-hour composite samples were collected during this short duration storm, which enabled sampling until the brook returned to its base flow. The maximum concentrations of total solids and phosphorus were similar to the February storm, but the maximum and mean total Kjeldahl-nitrogen was much higher, 1.80 mg/l and 0.86 mg/l, respectively.

The NOAA station at Worcester recorded only 0.06 inches of rain during the June 11 storm, but the peak concentrations of solids and nutrients were very high compared to other storm events (**see Table 4-3**). The suspended solids peaked at 226 mg/l, three times the level in other storms, and the mean concentration was 42 mg/l, twice the concentration from the other storms. Kjeldahl-nitrogen and phosphorus maximum concentrations were also very high. The peak phosphorus concentration was 0.57 mg/l, ten times the dry weather concentration. The peak flow from this storm was 21.6 cfs, 35 percent higher than the May 30 storm, although the storm volumes were comparable.

The following day, June 12, 0.48 inches of rain fell during the afternoon. The maximum phosphorus concentration was reduced to 0.29 mg/l, half the concentration of the previous day. However, the mean phosphorus concentrations were similar.

The June 19 sampling was taken during the increasing period of the storm flow, not throughout the whole storm event. Although traces of rain were recorded throughout the day, there was 0.55 inches of rain during a three-hour period. The concentrations of solids and nutrients were similar to the other storms, and at least twice the highest dry weather values (**see Table 3-1**).

TABLE 4-2

GATES BROOK STORMWATER STUDY

Water Quality Monitoring Data
Range of Observed Historical Values (1982 - 1989)
and
Range of Observed Sampled Values (1990 - 1991)

Parameter (All units in mg/l unless noted)	**1982 - 1989**	**1990 - 1991**
pH (SU)	6.6 - 7.9	6.1 - 7.6
Alkalinity (as $CaCO_3$)	12 - 64	14 - 49
Hardness (as $CaCO_3$)	18 - 105	2 - 95
Turbity (NTU)	0.25 - 95	0.2 - 14
Suspended Solids	N/T	<1 - 346
Total Solids	N/T	99 - 3112
Total Volatile Solids	N/T	<1 - 273
Color (Color units)	5 - 56	N/T
Conductivity (μmhos/cm)	71 - 550	53 - 1950
Chloride	21 - 207	18 - 530
Total Kjeldahl-Nitrogen	0.14 - 0.5	0.08 - 3.14
Ammonia-Nitrogen	0.019 - 0.11	<0.01 - 0.8
Nitrate-Nitrogen	0.9 - 2.5	0.25 - 2.0
Total Phosphorus	0.013 - 0.138	0.005 - 2.1
Ortho Phosphorus	0.012 - 0.119	N/T
Silica	2.2 - 4.0	N/T
Total Coliform Bacteria (colonies/100ml)	20 - 4600	N/T
Fecal Coliform Bacteria (colonies/100ml)	16 - 3900	38 - 30,000

N/T - Designates a parameter not analyzed

TABLE 4-3

GATES BROOK STORMWATER STUDY

Event Specific Nutrient Concentrations

Date	Flow (acre-feet)	Total Suspended Solids		Total Phosphorus		Total Kjeldahl-Nitrogen	
		Load (lbs)	EMC[1] (mg/l)	Load (lbs)	EMC (mg/l)	Load (lbs)	EMC (mg/l)
01/16/91	112	5088	16.7	16.7	0.055	100	0.328
02/07/91	103	4386	15.7	15.0	0.054	91.4	0.328
05/30/91	39	5420	51.7	16.4	0.157	95.5	0.911
06/11/91	2	254	49.3	0.8	0.158	4.8	0.941
06/12/91	26	6320	89.4	17.3	0.244	96.3	1.36
06/19/91	48	4388	33.6	13.5	0.103	79	0.604

[1] EMC denotes Event Mean Concentration

4.5 Model Calibration

Using the data which were collected in the field component of this project, calibration of the model was conducted in two phases. The hydraulic characteristics (stormwater quantity) were calibrated first. Daily average stream flow data were used to calibrate the model predictions of Gates Brook stream volume. The study design called for collection of storm flow data from October 1990 to October 1991. However, due to a number of mechanical and technical problems, continuous hydraulic data were not available for the entire study period. Good flow data records were available for the months of December 1990, January, May and June of 1991. Flow measurements for periods of up to two weeks were available for the remainder of the time. However, since the model uses a moving average calculation method, the "shorter" data records could not be used.

Comparison of observed data to the flows predicted by the model showed reasonable accuracy. Adjustment to the time of concentration for the devices is suggested for improve the calibration of the model, but was unnecessary in this case due to the accuracy obtained upon review of the moving daily averages within the program.

In order to calibrate the model to peak flows, it was necessary to consider some of the problems encountered collecting stormwater hydraulic data. As discussed previously, the flow gage was located at an existing 48" culvert. This simplified calculation of typical flows, but distorted measurements of higher intensity flows. When large storms occurred, the culvert restricted flows and ponding occurred upgradient of the culvert. There were also instances when the culvert was overtopped. These conditions limited the accuracy of data obtained for storm events in which flow exceeded 75 cfs. Exclusion of these storm events from the data set minimized the influence of the ponding and overtopping on observed peak flows. By considering these factors, and adjusting the data set accordingly, the observed peak flows corresponded within acceptable ranges to the predicted peak flows.

When the model is satisfactorily calibrated to the flow data, water quality data can be calibrated. P8 can estimate storm water quality concentrations for total suspended solids, total phosphorus, total Kjeldahl-nitrogen, copper, lead, zinc, and total hydrocarbons. Hydrocarbons were not analyzed during the field component of this project. Therefore, the model was calibrated for the remaining six water quality parameters.

The particle characteristics were initially assumed as median event-mean runoff concentrations taken from NURP studies, and provided in the model. The initial predictions were adjusted using the "Pollutant Load Scale Factor" in the program. This adjustment factor allows the model to more accurately predict loadings based on site-specific sampling. A reduction of the impervious fraction of the drainage area is suggested to be necessary and is suggested in the P8 documentation (Walker, 1990), to reduce predicted runoff flows when calibrating the model to site-specific ranges. As stated above the calibration resulted in reasonably accurate assessments.

The model uses an Event Mean Concentration (EMC) for each parameter to characterize pollutant concentrations in a storm event. The water quality data were reviewed in order to calculate observed EMC's. Flow data and water quality data are necessary to calculate an EMC. There were eleven events for which both data sets were collected. Flow readings which were collected for the October 15 event were unreliable, therefore the EMC's were not calculated for this date. EMC's were calculated for ten sampled storm events, and used to calibrate the model. The event mean concentrations for suspended solids, total phosphorus, and total Kjeldahl-Nitrogen for the sampled storms are shown in **Table 4-3**.

Of these observed storm events, the September events were not used because the NOAA rainfall data were not available on computer format at the time the model was run. Data from six storm events were determined to be consistent with observed characteristics, and appropriate for use in water quality modelling for the following reasons: the sampling was conducted during varied phases of the storm event (i.e. some samples were taken during the initial rainfall phase, the peak of the storm, while other samples were collected during the tail of the storm event), the flow monitoring was not continuous nor were the flow characteristics of the gaging station reviewed adequately during the formation of this study, high intensity localized summer storms influenced the correlation of the data at the gaging station at Gates Brook and the NOAA Station at Worcester Airport data.

Agreement with the observed information varied with the storm event. Some of the individual storm event predictions reflect the observed characteristics quite well, while other predictions are off by several orders of magnitude. Large differences between observed and predicted values occurred for storm events on June 30 and June 19. The discrepancies may be explained, in part, by the nature of these storms. The storms were typical summer storms: short, high-intensity, and localized. As noted earlier in Chapter 3, the rain data used for modelling were obtained from a rain gage located approximately eight miles from the water quality sampling and streamflow recording station. For these summer storms, the distance between rain gage and the sampling station may have introduced a significant error due to differences in precipitation in Worcester in West Boylston.

The accuracy of the flow data simulation was determined by comparison of the moving daily averages of the predicted versus the observed flows. A comparison of the predicted and observed/extrapolated annual storm volumes was conducted to assess annualized loading. The annual loading calculation was made using the USGS rainfall data for a total of 65 storms during the period between January 15 and June 20, 1991. The rainfall during the period was 20.25 inches, which is 47 percent of the annual rainfall. To estimate annual pollutant loadings the total loads computed for the period were multiplied by the reciprocal of 47 percent (2.13), to result in the approximate annual pollutant loading as shown below in **Table 4-4**

TABLE 4 - 4

GATES BROOK STORMWATER STUDY

P-8 Model Estimates of Annual Pollutant Loadings

Year	Flow (ac-ft)	Suspended Solids (lbs)	Total Phosphorus (lbs)	Total Kjeldahl-N (lbs)
1/91-6/91	1415	187680	609	2755
1990	3054	390820	1310	5982
1989	2075	306325	1023	4670
1988	2276	332370	1090	4945

The event mean concentration and the event-specific total pollutant loading as predicted by the P8 model correlated reasonably well with the observed storms. The P8 model predictions and the observed data for the six representative storm events are presented in **Table 4-5**. Precision of the model is determined by comparing model predictions with the observed values. The base flow and the event mean concentration are the most critical values used in the calibration of the P8 model. An evaluation of the parameters in more general characteristics within the Gates Brook subwatershed that are indicators of water quality. The values calculated by the P8 Program for annual phosphorus loading and average mean concentration of phosphorus were compared to a previous assessment conducted for MDC reported in "Wachusett Reservoir Taste and Odor Study" (Camp, Dresser & McKee, 1989), (CDM). The P8 model predicted annual phosphorus load and average mean concentration to be 1023 lbs/yr and .055 mg/l, respectively. The CDM study determined an average phosphorus concentration of 0.056 mg/l, and an annual phosphorus load from Gates Brook of 508 lbs/yr. The larger difference in predictions for loading is due to different storm volume predictions. However, the predictions show reasonable agreement considering that both studies were performed at a planning level.

TABLE 4-5

GATES BROOK STORMWATER STUDY

Predicted and Observed Storm Loadings

Date	Storm Volume (ac-ft)		Total Suspended Solids				Total Phosphorus				Total Kjeldahl-Nitrogen			
			EMC (mg/l)		Load (lbs)		EMC (mg/l)		Load (lbs)		EMC (mg/l)		Load (lbs)	
	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs
1/16	113	40	16.6	34	5088	3744	0.055	0.12	17	13	0.33	0.71	100	78
2/7	103	89	15.7	26.3	4386	6373.86	0.054	0.1	15	24.24	0.33	0.39	91	95
5/30	39	2.0	51.7	17	5420	92.48	0.157	0.08	16	0.44	0.91	0.94	95	5
6/11	1.9	2.0	49.3	129	254	684.22	0.158	0.36	0.8	1.91	0.94	1.8	5	9.6
6/12	26	4.7	89.4	86	6319	1092.41	0.244	0.11	17	1.40	1.36	0.2	96	2.5
6/19	48	5	33.6	30.2	4389	422.22	0.103	0.08	13	1.12	0.60	0.45	79	6.3
STUDY AVERAGE VALUES			28.8				0.089				0.52			

5.0 Stormwater Management

5.1 Stormwater Management Objectives--MDC

Prior sampling and water quality surveys have shown that stormwater is a major pollution source in the Wachusett Reservoir watershed. The principal pollutants associated with stormwater include solids, nutrients and bacteria. In the Watershed Protection Plan for the Wachusett Reservoir Watershed, (the "Plan"), the MDC and MWRA have identified urban runoff (stormwater) as a high priority threat to water quality in this watershed. The Plan has recommended that the development of protection measures for the treatment and/or control of stormwater should be a high priority. In order to develop a set of appropriate treatment, control or management actions which might represent such protection measures, it is first necessary to define a specific level of stormwater control, or, in other words, stormwater treatment/control objectives, which these treatment or management actions must achieve.

There are, broadly stated, two approaches which might be taken to define specific stormwater treatment objectives. These include the establishment of water quality based objectives and the use of technology based objectives.

The establishment of water quality based objectives is dependent on the availability of adequate water quality data for the particular receiving water to allow an assessment to be made as to the specific contribution of stormwater to the overall condition of that receiving water, and further, that an assessment can be made regarding the level of treatment or control of stormwater required to achieve a specific water quality condition in the receiving water. For example, a typical water quality based stormwater control objective might be stated as follows:

> "In order to meet {Class A, SWTR} water quality criteria in the Wachusett Reservoir, {pollutant_____} must be reduced to {x}{units}; or be reduced by {x%} of the current {monthly, seasonal, annual} stormwater loadings."

This approach typically leads to the establishment of a control level which is independent of the ability of available treatment or control measures to achieve. The establishment of a water quality based control objective is also independent of the cost which might be required to achieve that objective. The use of a water quality based approach to setting stormwater control objectives also presumes that there is sufficient water quality data or a reliable analytical framework (i.e., a "model"), or both, to predict alternative outcomes in terms of attainment of water quality objectives.

Alternatively, the use of technology based treatment or control objectives is more or less independent of receiving water quality. This approach presumes that various technologies or best management practices are sufficiently well-documented as to their ability to remove a certain level of contaminants that their use will result in some level of water quality improvement. This allows analysis when the level of receiving water quality improvement is not capable of being quantitatively predicted. A typical technology based stormwater control objective might be stated as follows:

> "The application of this {stormwater treatment/control/BMP} will reduce the {monthly, seasonal, annual} stormwater load by {x %}."

It is the stated goal of the DWM to move toward the development of water quality based objectives for defining required levels of stormwater treatment and control. However, the Division is limited at the present time by the limitations of available receiving water quality data in the Wachusett Reservoir in response to stormwater loadings. The Taste and Odor Control Study, (CDM, 1989), made some generalizations which may be useful in terms of relating a technology based objective to some level of water quality improvement. However, that is insufficient for use as a basis for defining a water quality based stormwater control objective.

The data gathered for Gates Brook as part of this study will be useful for defining a water quality based objective specific to achieving a particular level of improvement in Gates Brook. However, the Division has not yet developed a receiving water quality model for Gates Brook which would allow an assessment of the level of water quality improvement which might be achieved by the use of alternative treatment/control devices. The P8 model preliminarily evaluates the effectiveness of alternative devices in reducing current stormwater loads being discharged into Gates Brook. Such use of the P8 model will allow prediction of overall pollutant loading reductions which can be achieved by alternative treatment and BMP measures.

Based on these considerations, the Division has decided to utilize the P8 modelling program to evaluate the level of reduction in stormwater pollutant loadings that might be achieved by the use of various stormwater treatment/control devices and to rely on the use of a technology based approach to stormwater control objectives until such time as adequate water quality data and modelling capability is available to enable the Division to achieve its goal of developing water quality based control objectives.

5.2 Review of Structural Controls

The P8 model has been designed to simulate water quality characteristics associated with a variety of structural treatment devices. The model has the capacity to simulate detention ponds (extended, wet, and dry), infiltration basins, flow splitters, swales, and buffers. Since this study is focused on Gates Brook at the reservoir, and that the storm flows are in concentrated flow, only the incorporation of detention ponds and filtration basins were reviewed. Consideration of swales and buffers are only appropriate where flow is shallow and slow-moving. The addition of upstream devices to improve the water quality is encouraged, but is beyond the scope of this study.

The P8 model has the capability to size a specific treatment device based upon inputted values of the predicted flow and a removal efficiency for a specified particle class or a removal efficiency for total suspended solids (TSS). TSS removal efficiencies of 70% and 85% were incorporated in the original software because of regulatory requirements imposed upon the Naragansett Bay analysis that the program was designed to conduct. The 85% TSS removal efficiency was chosen in the initial study due to the reduced violation frequencies of other pollutants, particularly the copper loading and to be consistent with the goals of the Narragansett Bay Project.

The storm data from the Worcester Airport for the period from December 1, 1990 through June 20, 1991 were used to evaluate the preliminary sizing of the treatment devices to be studied in the future. This study does not mean to infer that the size of these BMP's is adequate to control storm flow from large events, i.e. the 100-year return frequency storm, that typical detention basins are designed to accommodate. The devices reviewed were the following: wet detention pond with five feet of flood storage, a dry detention pond with five feet of flood storage, and infiltration basin with five feet of storage.

The inclusion of these treatment device sizings was conducted as an exercise for usage of the P8 Model in the future. The determination of a specific treatment method and its efficiency is beyond the scope of this project. The purpose of this study is to establish relative sizes of different types of treatment devices, based on the subwatershed data currently available. Information that is needed to make a decision for defining a more specific device includes: soil type and permeability at the device location, permitting constraints, specific pollutant removal needs, more specific stormwater sampling data, site-specific physical constraints, and construction costs.

Table 5-1 describes the estimated pollutant removal efficiencies of specified BMP's. These efficiencies are based on a modelled removal objective of 85 percent of the TSS.

TABLE 5 - 1

GATES BROOK STORMWATER STUDY

Estimated Pollutant Removal Efficiencies

PARAMETER	TREATMENT DEVICE ALTERNATIVES			
	DRY POND			
	9.2 Acres with riser	15.3 Acres with Weir	WET POND 24.3 Acres	INFILTRATION BASIN-10 Ac.
TSS	85	85	85	84
TP	63	63	51	64
TKN	59	59	44	61

As a point of comparison, DEP is currently considering requiring stormwater detention equal to the volume generated by multiplying the impervious portion of the drainage area by a depth of two inches. Using the data input into the program, and assuming a basin depth of 5 feet, the area of a detention basin for all the stormwater from this watershed would have a total surface area of approximately 17 acres. No assessment of the pollutant removal efficiency of such a structure has been conducted, nor has an assessment of rationale, efficiency or the cost-benefits of such an extensive design criteria been done.

5.3 STORMWATER TREATMENT/CONTROL MANAGEMENT OPTIONS

The MDC has a long history of attention to water pollution abatement measures within the water supply system. Within the Wachusett Reservoir watershed, the approaches viewed at turn of the century approaches focused on diversion of tributaries and direct treatment. Such systems can still be found in operation at the Sterling Filter Beds and at the Marlborough Filter beds at the Sudbury Reservoir. Detailed designs for a diversion dam on Gates Brook and filter bed system near its mouth were designed around 1910 (**see Figure 5-1**). Evidence of similar systems can be found throughout the Wachusett Reservoir watershed including the Campground Road filter beds in Sterling, the West Boylston filter beds and the Gates Village interceptor berm and filter beds (circa 1906 - 1908).

Based on the use of rapid sand filter systems in the past, the Division has identified four basic options as approaches to evaluating stormwater control/treatment options on a watershed or subwatershed basis. These include the following and are depicted in **Figure 5-2**:

a. Centralized Stream Diversion with Treatment (**Figure 5-2a**)

The centralized diversion and treatment systems were developed as a response to pollutant loads which were observed to impair reservoir water quality on a regular basis, without regard to particular weather conditions such as storms. Such systems met the primary sanitary protection objective for surface water supply reservoirs by placement of a "barrier" between the sources of pollution and the reservoir. One such system which was constructed and operated for many years is the Marlborough Brook Filter Beds at the Sudbury Reservoir in Marlborough. The Gates Brook Diversion and Filter Bed system, which was designed but never built, would have intercepted all of the dry weather flows in the brook and a significant portion of the stormwater flows prior to their entering the reservoir for treatment by a combination of sand and gravel coarse filters. Relative to the attainment of the objectives of the Surface Water Treatment Rule and the most complete barrier for protection of the reservoir, this approach represents perhaps the most effective and efficient method available.

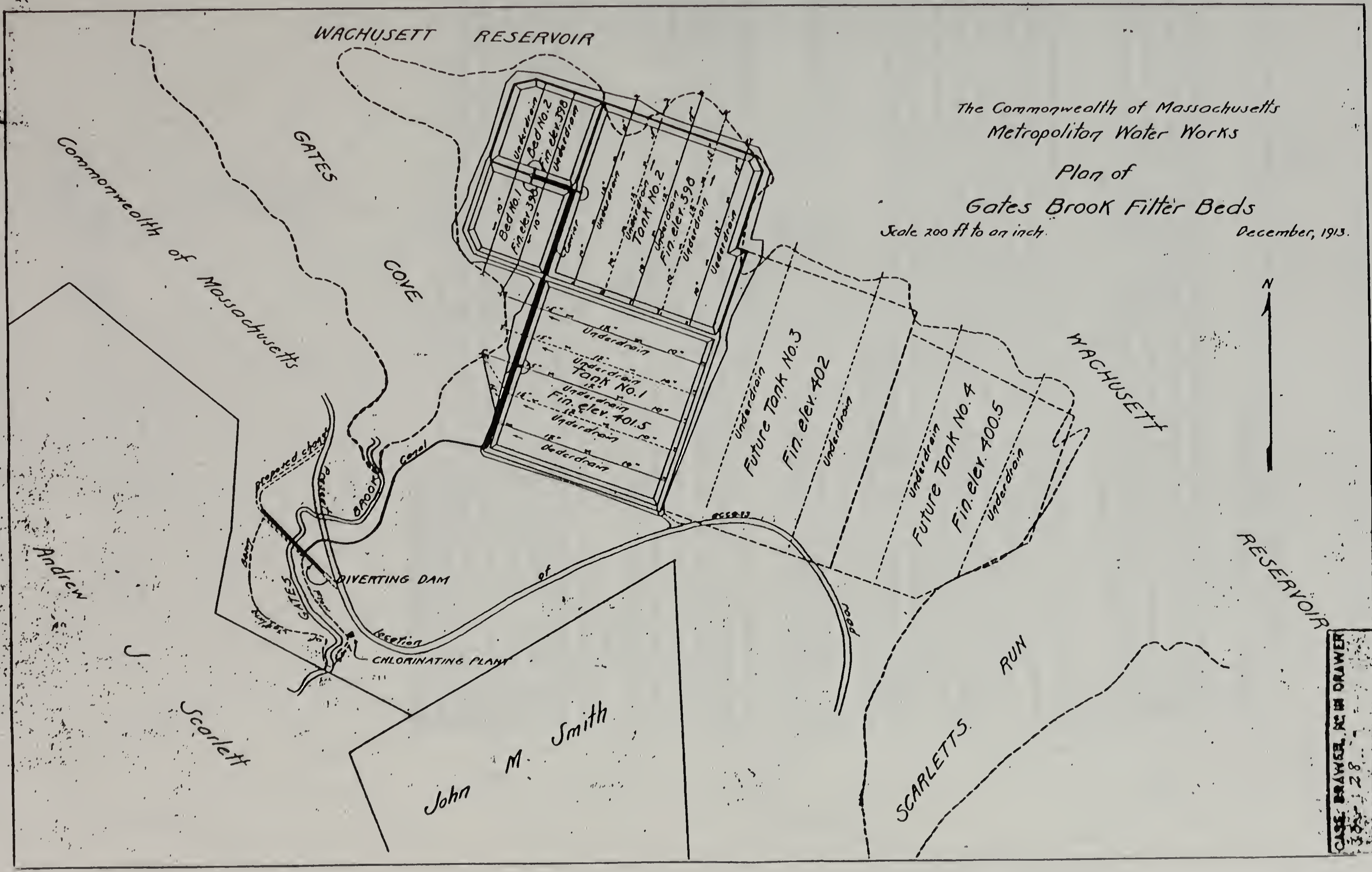
b. Decentralized Stream Diversion with Treatment (**Figure 5-2b**)

The decentralized systems were developed in response to site-specific water pollution problems in isolated portions of the contributing drainage basins and subwatersheds. The Sterling Filter Beds were designed in response to the heavy organic and solids loads imposed by the waste discharge from a cider mill which operated until the mid 1980's. (The plant closed when it was told it required an NPDES discharge permit by the USEPA.)

FIGURE 5 - 1

GATES BROOK STORMWATER STUDY

Gates Brook Filter Bed Design (1910)
(Not To Scale)



c. Centralized Stormwater Collection System with Treatment Devices and/or Best Management Practices (**Figure 5-2c**)

Centralized stormwater collection systems are those typical of heavily developed urban areas and include such elements as street/curbside inlets, catchbasins, storm sewers and outfalls at the most downstream point in the contributing drainage basin. These systems are generally built, operated and maintained by a municipality. Presently, there are no centralized stormwater collection systems within the town of West Boylston.

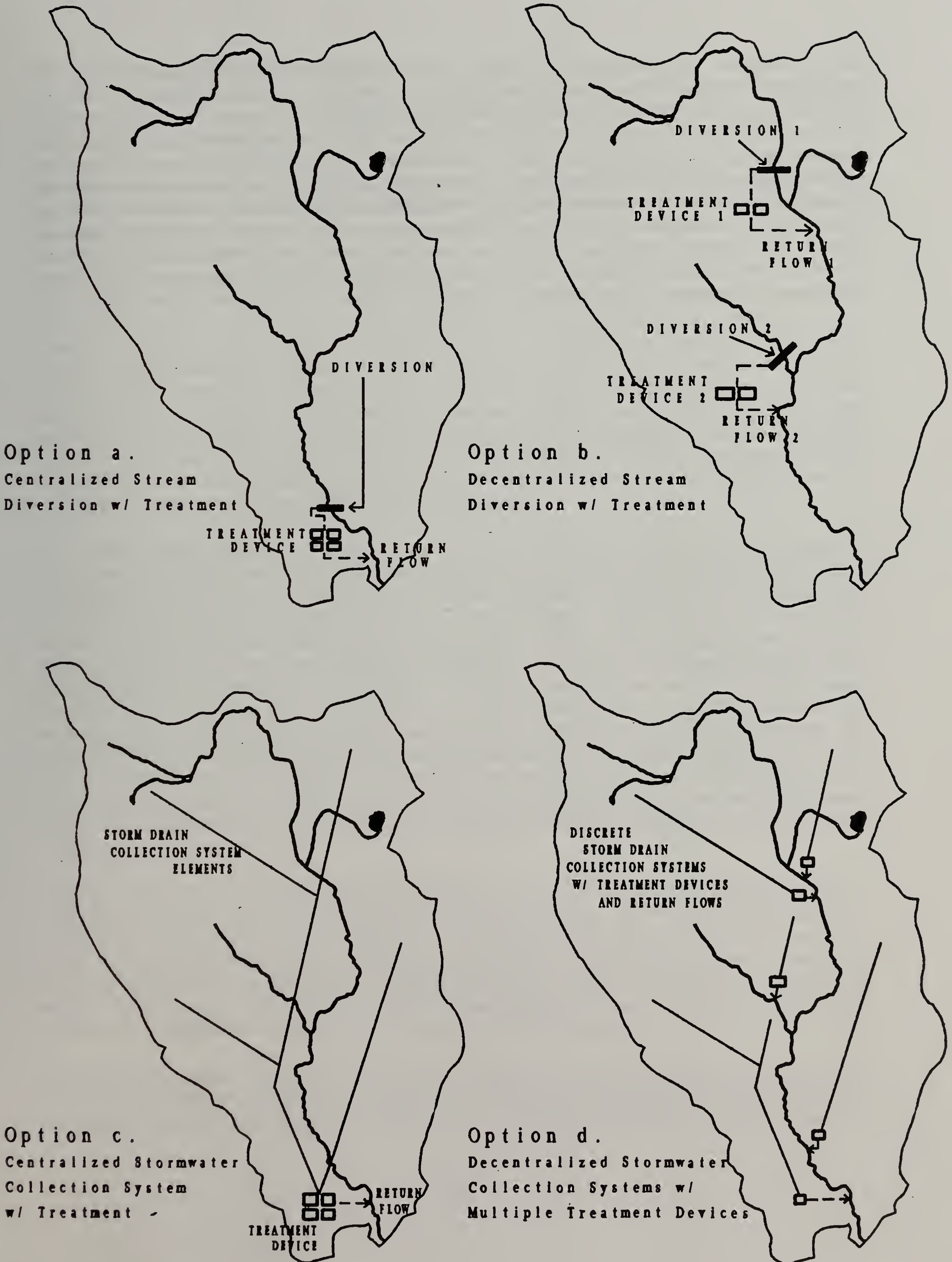
Historically, these systems did not include provision for treatment of stormwater prior to discharge to the receiving water. With the increased focus on control of pollution from "nonpoint" sources since the mid 1970's, including urban runoff, pollution control measures have generally been oriented to "Best Management Practices" (BMP's) such as street sweeping and catch basin cleaning as opposed to "end of pipe" treatment measures. The "country drainage" approach to road construction prevalent in West Boylston, which typically avoids the installation of gutters in favor of directing washoff off the road surface directly into adjoining free-draining sand and gravel areas, presents a substantial impediment to the use of this approach in the Gates Brook drainage area.

d. Decentralized Stormwater Collection Systems with Treatment Devices and/or Best Management Practices (**Figure 5-2d**)

Decentralized stormwater collection systems are typically constructed in conjunction with developing areas of a community. Systems may be constructed by the municipality in response to localized flooding or road condition problems or may be installed by the developer of a subdivision or industrial/commercial park or development project. These systems typically serve a relatively small, well-defined contributing drainage area and include similar elements as are found in larger stormwater systems as described above.

Such systems generally rely on the availability of a nearby downgradient stream or wetland area for the discharge of collected stormwater. Treatment is rare with reliance on BMP's more typical. With relatively few exceptions, such as the storm drain systems for the Fair Plaza and Wachusett Plaza, there are no decentralized stormwater collection systems serving West Boylston. The reliance on country drainage and the absence of curbing and gutters in the streets limits the potential applicability of this approach in West Boylston. In contrast, the town of Holden currently has several areas of town which are served by discrete stormwater collection systems.

Figure 5-2 Stormwater Management Options



Option a.
Centralized Stream
Diversion w/ Treatment

Option b.
Decentralized Stream
Diversion w/ Treatment

Option c.
Centralized Stormwater
Collection System
w/ Treatment

Option d.
Decentralized Stormwater
Collection Systems w/
Multiple Treatment Devices

Note: Illustrations Depict a Typical Watershed

The requirements and restrictions of current environmental protection regulations such as the Massachusetts Wetlands Protection Act and MEPA may preclude or seriously impair the ability of the MDC to utilize the stream diversion approaches associated with options a. and b. described above. Based on the information gathered within the scope of this investigation, and the results of the modeling strategy using the P8 model, it is recommended that the Division proceed to develop a comprehensive stormwater management plan for the Gates Brook subwatershed including consideration of all of the stormwater management options described above. An important element of the scope of the recommended plan will need to address the effects of current regulations and policies which govern stormwater as well as structural controls and surface and groundwater discharges from treatment devices. A more detailed review of current stormwater and related regulations is presented in Chapter 6 of this report.

6.0 Current Stormwater Regulation

6.1 Regulatory Authority

The Massachusetts Department of Environmental Protection (MADEP) has regulations which address stormwater contamination and has the ability through these regulations to require a discharge permit to control the amount of pollutants discharged from stormwater systems. These regulations are briefly discussed below.

The regulations for the MADEP Surface Water Discharge Permit Program are contained in 314 CMR 3.00. Section 3.04(2)(a)(1) of that document and defines stormwater discharges as "...a conveyance or system of conveyances primarily used for collecting and conveying storm water runoff...and which discharges storm water contaminated by contact with process wastes, raw materials, toxic pollutants, hazardous substances, or oil and grease...(or) located in an industrial plant or in plant associated areas...". Such stormwater discharges must have a current, valid permit to discharge into waters of the Commonwealth. The Director of the Division of Water Pollution Control may designate other discharges as "storm water discharges" on a case-by-case basis if it is determined that the discharge is or may be a significant contributor of pollution..." This regulatory authority allows the MADEP to require stormwater permits where appropriate.

The Massachusetts Surface Water Quality Standards (314 CMR 4.00) contain provisions designed to protect water supply systems, including tributaries to those water bodies. This protection is aimed at Outstanding Resource Waters (ORW's) and provides a safeguard and regulatory control for water supplies. The regulations can prohibit discharges which are likely to cause degradation due to runoff and other pollutant inputs. Section 4.04 (3) of the WQS contains the antidegradation provisions which prohibit the discharge of new or increased discharge to an Outstanding Resource Water, unless the discharge is determined by the Director "...to be for the express purpose and intent of maintaining or enhancing the resource for its designated use..." Existing discharges to ORWs shall cease said discharge unless it is shown that the highest and best practical method of treatment is provided. For stormwater, the installation of stormwater control systems (e.g. detention basins, drainage swales) and the setback of the discharge from the receiving water are required. MADEP is developing a program to review the stormwater systems and ensure that the permit conditions are achieved. Wachusett Reservoir and all tributaries to the reservoir, including Gates Brook, are designated as Class A, ORW waters.

The U.S. Environmental Protection Agency (USEPA) is responsible for issuing NPDES permits in Massachusetts, as this state has not assumed program delegation. The NPDES discharge permit program is administered by USEPA Region I with MADEP certifying permit conditions according to the requirements of Section 401 of the Federal Clean Water Act. MADEP reviews the conditions of the permit and certifies the permit unconditionally or with special conditions, if appropriate. In addition, MADEP signs each NPDES permit, thus creating separate state and USEPA permits which provide equal regulatory and enforcement authority for both agencies.

To address the pollutant problem of storm water discharges and to avoid a massive administrative burden, USEPA has issued a general stormwater permit for construction sites over five (5) acres and storm water associated with specific industrial activities (classified by USEPA according to Standard

Industrial Code). These permits were promulgated by USEPA under the authority provided in the Clean Water Act and were published in the Federal Register on September 25, 1992. MADEP certified the general permits with special conditions for discharges to ORWs and coastal Areas of Critical Environmental Concern (CACEC). The conditions disallow coverage under the general permit for new discharges of stormwater to ORWs and require existing discharges to provide discharge setbacks which will maximize infiltration and overland flow and eliminate the direct discharge of stormwater to the receiving stream. The intent is to apply Best Management Practice (BMP) controls and structures to reduce direct stormwater inputs and to allow for maximum infiltration into groundwater systems. The general permit is obtained by submittal of a Notice of Intent (NOI) to USEPA. A copy of the NOI and a fee transmittal form (with a fee of $50.00) should be submitted to MADEP/OWM if the discharge is to an ORW or CACEC.

6.2 Compliance Approach

MADEP has the ability to take enforcement action against dischargers who are in violation of the above discussed regulations or who circumvent those regulations. Enforcement is initiated by the MADEP regional office and often involves the State Attorney General's Office.

It is the intention of MADEP (with input from and cooperation with MDC) to take the proactive approach to stormwater control, that is to inform all parties of the permit requirements and to institute a program to review the compliance with the stormwater permit requirements and the implementation of BMPs as required.

MADEP/OWM has applied for a 104b3 grant from USEPA which will be used to implement a stormwater outreach program (including the development of an informational brochure), review pollution prevention plans, and conduct an evaluation of compliance with the stormwater regulations in the Nashua River Basin (which includes Gates Brook and Wachusett Reservoir).

It is the goal of MADEP to utilize the USEPA general permit for stormwater control in the Gates Brook watershed (as well as the rest of the state) and to require individual NPDES stormwater permits when conditions are such that the general permit will not sufficiently control the impact of stormwater. The stormwater NPDES permits do not directly address the MADEP wetland regulations; however, those regulations, when properly applied, contribute to the overall control of water quality and resource protection. MADEP views the wetland regulations as complementary to the stormwater permit program.

7.0 CONCLUSIONS AND RECOMMENDATIONS

This report summarizes the results of an intensive study of stormwater in the Gates Brook subwatershed. This study has demonstrated that the stormwater pollutant loadings from the Gates Brook subwatershed are significantly greater than the pollutant loads associated with average, dry-weather conditions. The analysis of stormwater impacts on Gates Brook and the Wachusett Reservoir are complicated by the presence of numerous faulty on-site wastewater disposal systems throughout the contributing drainage basin. Inadequately renovated leachate from such faulty systems mixes with stormwater by both direct overland flow and by subsurface flow into Gates Brook. The assessment of stormwater impacts on both Gates Brook and the Wachusett Reservoir as receiving waters is limited by the lack of suitable receiving water quality models for these water bodies. Until a modeling strategy becomes available, the development of stormwater management strategies will be constrained to consideration of technology based stormwater management and treatment objectives. Regardless of such constraints, this study clearly demonstrates the need to proceed with the development of a comprehensive stormwater management plan for the Gates Brook watershed and for similar heavily developed subwatersheds within the Wachusett Reservoir watershed.

Specific conclusions and observations regarding water quality; sampling strategies and modeling are presented in the following section. The final section of this chapter contains specific recommendations for future stormwater management planning and the integration of stormwater management considerations with other watershed protection actions in the remainder of the Wachusett Reservoir watershed.

7.1 CONCLUSIONS

WATER QUALITY IMPACTS

Stormwater pollutant loadings were substantially higher than documented dry weather loads as reflected in the following observations:

1. Concentrations of total phosphorus ranged from two to six times higher than the average dry weather concentrations. While ammonia-nitrogen and nitrate-nitrogen levels were comparable to dry weather levels, total Kjeldahl-nitrogen (TKN) was significantly higher. On one occasion, the TKN concentration was 28 times higher than the average dry weather concentration observed over the sampling period.

2. Bacteria levels were significantly greater during storm events than during routine sampling. Bacteria levels were observed to increase gradually as storm events progressed, rather than indicating a first flush response. This may be an indication of transmission from inadequate treatment of domestic sanitary flows by on-site wastewater disposal systems and thereby increase transmission of bacterial loads via groundwater.

3. During storm events when the total event precipitation was less than 0.75 inches, the peak stormwater discharge ranged from two to eight times higher than the initial baseflow.

4. Concentrations of various water quality constituents were observed to generally meet current drinking water standards as indicated in the following:

a. The pH went below the drinking water criteria on only two occasions. The chloride standard was exceeded once during a storm which followed road salt application.

b. Drinking water criteria for lead, chromium, nickel and mercury were generally well-below the standards. However, the criteria for each of these constituents were violated once, during separate events.

c. Iron and magnesium concentrations routinely met the drinking water criteria.

5. Concentrations of various water quality constituents were observed to exceed the applicable surface water quality criteria for aquatic life as follows:

a. Total alkalinity was generally at or slightly above the aquatic life criteria.

b. Average storm related concentrations of aluminum, copper and lead exceeded the chronic aquatic life water quality criteria by a factor of four or more toxic units. Mercury exceeded the chronic aquatic life criteria by 33 toxic units. Total chromium and iron generally equalled or slightly exceeded the chronic aquatic life criteria. Although storm average concentrations of cadmium, chromium and zinc were below the acute aquatic life toxicity criteria, the maximum observed concentrations of these elements were observed to exceed the acute criteria.

P8 MODEL APPLICATION

The following conclusions were reached based on the application of the P8 model to the Gates Brook watershed using the data gathered within this study:

6. The P8 model is appropriate for analyzing present and projected stormwater loadings. The model reliably predicted flows and pollutant loadings from this watershed within reasonable ranges.

7. The P8 model is not suitable and can not be used for assessment of bacterial loads and impacts.

8. Preliminary assessment and "order of magnitude" sizing of alternative treatment devices suggests that wet basins may be the most appropriate stormwater treatment method, but further evaluation is required to determine sizing, outfall and discharge characteristics and permitting requirements.

9. Due to the simplifying assumptions related to the hydraulic characteristics of the various treatment devices analyzed, the P8 model results should be subjected to further hydraulic analysis using the TR20 model. The TR20 model analysis will allow verification of structural integrity and reliable inflow-outflow storm event sizing of treatment devices.

7.2 RECOMMENDATIONS

Based on the conclusions stated above and as may be found within the text of various other sections of this report, the Division and DEP/OWM offer the following recommendations regarding further stormwater management planning for the Gates Brook subwatershed; future stormwater management planning in other developed subwatersheds within the Wachusett Reservoir watershed; the use of the P8 model and the development of suitable stream and reservoir receiving water quality models; and the conduct of future stormwater sampling programs.

1. STORMWATER MANAGEMENT PLAN FOR GATES BROOK SUBWATERSHED

The Division, in consultation with DEP and the town of West Boylston, should proceed with the development of a stormwater management plan for the Gates Brook subwatershed incorporating the results of the P8 modeling conducted as part of this study and incorporating the detailed evaluation of stormwater treatment/control management options as presented in section 5.3 of this report. This recommended plan should include a detailed evaluation of available BMP's as an integral element of a comprehensive stormwater control strategy. The study should also include consideration of local zoning and non-zoning controls which might be related to land use and land use intensity within watersheds which exceed some overall level of imperviousness or other measurement, and which correlates with development intensity and stormwater impacts. Finally, this plan should address institutional, financial and legal mechanisms required for plan implementation and long-term maintenance and reliability.

2. STORMWATER MANAGEMENT PLAN IN THE WACHUSETT RESERVOIR WATERSHED

The results from this study serve to reinforce the importance of stormwater management as a high priority for the protection of the Wachusett Reservoir as has been previously noted in the Watershed Protection Plan for the Wachusett Reservoir Watershed. It is recommended that the Division proceed to initiate a comprehensive stormwater management planning process for the remainder of the Wachusett Reservoir watershed using the P8 model and such updated land use and water quality information as may be available through the MDC/EOEA GIS data system and the water quality programs of the DWM. This initiative should focus on the identification of key subwatersheds whose land use and development characteristics indicate that stormwater is likely to be a significant source of pollutant loading within the watershed system. This planning program should have as one of its critical outputs a listing and prioritization of critical subwatersheds within the Wachusett Reservoir watershed for the development of basin-specific stormwater management plans similar in scope to that proposed above for the Gates Brook subwatershed. As suggested in the Quinapoxet Sanitary Survey, completed by the Division in 1992, there are several areas within the town of Holden within the Quinapoxet River subwatershed which are likely candidates for examination within the scope of this proposed planning effort.

3. STORMWATER AND RECEIVING WATER QUALITY MODELING

As discussed in section 5.1, the Division has selected the P8 model as the basis for evaluating stormwater pollutant loadings on a subwatershed basis. The Division also recognizes the desirability of moving toward a water quality based approach to establishing stormwater and other watershed management control objectives. This requires the selection and use of appropriate receiving water quality models for both the tributaries within the watershed system and the reservoir itself. Models such as STREAM (developed for the DEP-DWPC); RECEIVE; or QUALIIe may be appropriate for river and stream environments. Multi-dimensional models such as CEQUAL2 or RECEIVE3.0 may be suitable for reservoir modeling. The selection, calibration and use of any of these models needs to consider the model data requirements, the extent of data available to satisfy model input requirements, and the ability of the DWM to acquire additional data which may not be currently available to meet model input requirements. This activity may be appropriate as a subject for joint research involving the Division and the University of Massachusetts Department of Civil and Environmental Engineering.

4. FUTURE STORMWATER SAMPLING PROGRAMS

A considerable effort went into the acquisition of field data for this project. The study team has several specific recommendations which should be adopted into a program of standard procedures for the collection of stormwater data by both DEP/OWM and the DWM. Recommendations include the following:

1. Sampling station selection must provide for reliable flow measurement during all reasonably foreseeable flow conditions. Conditions such as ponding upstream of the measurement device or by-pass of the device should be reviewed and corrected prior to initiation of data collection.

2. Assigned sampling staff must be instructed in the proper use of the equipment and its limitations prior to commencement of field operations.

3. An adequate period of time, on the order of two to ten weeks, must be built into the schedule for the installation and calibration of field equipment. The study team needs to be confident of the accuracy and reliability of flow data and equipment operation before sampling.

4. Stormwater sampling program design needs to include detailed protocols and specification of field procedures based on the specific parameters for which data are being collected. It is specifically recommended that bacteria samples be collected manually and that bacteria samples be processed within six to eight hours of their collection.

5. Based on the use of the automatic samplers which were utilized in this study, the following sampling procedure is recommended to enable capture of first flush impacts as well as storm event total loadings:

> Two automatic samplers are required. Sampler #1 is to be programmed for non-uniform time sampling (discrete samples as defined in the sampling protocol). Sampler #2 is to be programmed for uniform, multiplex composite samples (four samples per bottle every fifteen minutes), initiated upon completion of Sampler #1 sampling sequence. Sampler #1 sampling sequence should be initiated at a predetermined specified minimum flow.

6. A tipping bucket rain gauge should be located within the contributing drainage basin within which samples are being collected. Establishment of a specific antecedent dry period should be specified as part of the sampling program. Based on the observations made during this study, a period of two days over which less than .05 inches of rainfall per day was adequate to distinguish pollutant loads associated with separate storm events.

REFERENCES

American Public Health Association. 1985. Standard Methods for the Examination of Water and Wastewater, 16th edition. Washington, DC.

American Water Works Association. 1982. introduction to Water Quality analyses Principles and Practices of Water Supply Operations. AWWA, Denver, CO.

American Water Works Association (AWWA) Research Foundation. 1991. Effective Watershed Management for Surface Water Supplies. Denver, Colorado.

Anderson, D. G. 1970. Effects of Urban Development of Floods in Northern Virginia. U.S. Geological Survey Water Supply Paper 2001-C. Washington, DC.

Athayede, D.N. et al. 1983. Results of the NURP Program, Volume I - Final Report. USEPA, Water Planning Division, Washington, DC, NTIS PB84-185552.

Brackley, R. A. and Bruce P. Hansen. 1977. Water Resources of the Nashua and Souhegan River Basins, Massachusetts. US Geological Survey, Atlas HA-276.

Brady, Nyle C. 1990. The Nature and Property of Soils. 10th ed. New York: McMillan Publishing Company.

Borland International, Inc. 1989. Quattro Pro User's Guide. Scotts Valley, CA.

Camp, Dresser & McKee (CDM). 1989. Wachusett Reservoir Taste and Odor Study. Prepared for the Metropolitan District Commission, Watershed Management Division.

Central Massachusetts Regional Planning Commission. 1979. Areawide Water Quality Management Plan.

Donigian, A.S., Jr., J.C. Imhoff, B. Biknell, and J.L. Kittle Jr., "Guide to the Application of the Hydrologic Simulation Program - Fortran (HSPF)", USEPA, Athens Environmental Research Laboratory, EPA-600/3-84-065, 1984.

Driscoll, E. D., "Detention and Retention Controls for Urban Runoff", in B. Urbonas and L.A. Roesner, "Urban Runoff Quality - Impact and Quality Enhancement Technology, American Society of Civil Engineers, pp. 381-393, 1986.

Durum, W.H. 1974. Occurrence of Some Trace Metals in Surface and Groundwaters. In: Trace Metals in Water Supplies: Occurrence, Significance, and Control. Proceedings, 16th Water Quality Conference, University of Illinois, Urbana.

Fabos, Julius Gy., Jack Ahern, and John Mullin. 1990. An Examination of the Effectiveness of Land Use Controls for Protecting the Wachusett Reservoir Watershed. Prepared for the Massachusetts Water Resources Authority by the METLAND Research Group in cooperation with the Environmental Institute, University of Massachusetts, Amherst.

Galvin D.V. and R.K. Moore. 1982. Toxicants in Urban Runoff: Report to US EPA Nationwide Urban Runoff Program. Seattle, WA.

Huber, Wayne C. and Robert E. Dickinson. 1992. Stormwater Management Model Version 4.20 User's Manual. EPA 600/3-88/001A.

IEP, Inc. 1982. Holden Municipal Groundwater Resource Analysis and Protection Study, Holden, MA.

IEP, Inc. 1990. P8 Urban Catchment Model User's Manual Version 1.1. Prepared for the Narragansett Bay Project, Providence, RI.

JTC Environmental Consultants. 1982. Final Report: Priority Pollutant Analysis. Prepared for Metropolitan Washington Council of Governments. Washington, DC.

Leopold, L.B. 1968. Hydrology for Urban Planning: A Guidebook on the Hydrological Effects of Land Use. U.S. Geologicl Survey Circular 554.

MacConnell, William P. and William Niedzwiedz. 1987. Remote Sensing 20 Years of Change in Worcester County, Massachusetts, 1951-1971. Massachusetts Agricultural Experiment Station, Research Bulletin Number 625. University of Massachusetts, Amherst.

Massachusetts Department of Environmental Protection. 1989a. Nonpoint Source Management Plan. Division of Water Pollution Control, Technical Services Branch, Westboro, MA.

Massachusetts Department of Environmental Protection, Lawrence Experiment Station. 1989b. Standard Operation Procedures: Inorganic Chemistry. Division of Environmental Analysis, Lawrence, MA.

Massachusetts Department of Environmental Protection. 1990. Massachusetts Surface Water Quality Standards. Division of Water Pollution Control, Technical Services Branch, Westboro, MA.

Massachusetts Division of Water Pollution Control. 1989. Basin Program Standard Operation Procedures for River and Stream Monitoring. DWPC, Technical Services Branch, Westboro, MA.

Massachusetts Water Resources Authority. 1990. Climatological data for the Wachusett Reservoir Watershed.

Metropolitan District Commission. 1990. Southern Wachusett Sanitary District Sanitary Survey. MDC Division of Watershed Management.

Metropolitan District Commission and Massachusetts Resources Authority. 1991a. Watershed Protection Plan for Quabbin Reservoir and Ware River Watershed. Prepared with the assistance of Rizzo Associates, Inc.

Metropolitan District Commission and Massachusetts Resources Authority. 1991b. Watershed Protection Plan for Wachusett Reservoir Watershed. Prepared with assistance of Rizzo Associates, Inc.

National Academy of Sciences, National Academy of Engineering. 1974. Water Quality Criteria, 1972. USGPO, Washington, DC.

National Research Council, Safe Drinking Water Committee. 1977. Drinking Water and Health. National Academy of Sciences, Washington, DC.

National Technical Advisory Committee to the Secretary of the Interior. 1968. Water Quality Criteria, USGPO, Washington, DC.

Oberts, G. L. 1985. "Magnitude and Problems of Nonpoint Pollution from Urban and Urbanizing Areas" in: "Proceedings of Nonpoint Pollution Abatement Symposium, Milwaukee, WI, April 20-23, 1985, pp. 1-12".

Occoquan Watershed Monitoring Lab (OWML). 1983. Final Contract Report: Washington Area NURP Project. Prepared for Metropolitan Washington Council of Governments, Manassas, VA.

Pitt, R. 1985. Characterizing and Controlling Urban Runoff through Street and Sewerage Cleaning. Prepared for U.S. Environmental Agency. EPA 600-52-85-038.

Schueler, Thomas R. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Metropolitan Washington Council of Governments, Washington, DC.

Snoeyink, V.L. and D. Jenkins. 1980. Water Chemistry. John Wiley & Sons, New York.

Stewart, Judith C., Ann T. Lemley, Sharon I. Hogan, and Richard A. Weismiller. 1989. Health Effects of Drinking Water Contaminants. Cornell University and The University of Maryland under sponsorship of the USDA Extension Service. Cooperative Extension System Water Quality Fact Sheet 2.

Taylor, W. H. and Charles F. Holtz. 1985. Soil Survey of Worcester County, Massachusetts, Northeastern Part. USDA, Soil Conservation Service.

Tighe & Bond. 1989. Wachusett Reservoir Pollution Investigation April 1987 - March 1988. Final Report. Prepared for Metropolitan District Commission.

U. S. Environmental Protection Agency (USEPA)

----------. 1976. Methodology for the Study of Urban Storm-generated Pollution and Control. EPA 600/2-76-145. Office of Research & Development, Cincinnati, OH.

----------. 1980. Ambient Water Quality Criteria for Zinc. EPA 440/5-80-079. Office of Water Regulations and Standards, Washington, DC.

----------. 1983. Results of the Nationwide Urban Runoff Program. Vol. I. Final Report. Water Planning Division, Washington, DC.

----------. 1985a. Ambient Water Quality Criteria for Arsenic - 1984. EPA 440/5-84-033. Office of Water Regulations and Standards. Washington, DC.

U. S. Environmental Protection Agency (USEPA)

----------. 1985b. Ambient Water Quality Criteria for Cadmium - 1984. EPA 440/5-84-032. Office of Water Regulations and Standards. Washington, DC.

----------. 1985c. Ambient Water Quality Criteria for Chromium - 1984. EPA 440/5-84-029. Office of Water Regulations and Standards, Washington, DC.

----------. 1985d. Ambient Water Quality Criteria for Copper. EPA 440/5-84-031. Office of Water Regulations and Standards, Washington, DC.

----------. 1985e. Ambient Water Quality Criteria for Lead - 1984. EPA 440/5-84-027. Office of Water Regulations and Standards, Washington, DC.

----------. 1985f. Ambient Water Quality Criteria for Mercury - 1984. EPA 440/5-84-026. Office of Water Regulations and Standards, Washington, DC.

----------. 1986a. Ambient Water Quality Criteria for Nickel - 1986. EPA 440/5-86-004. Office of Water Regulations and Standards, Washington, DC.

----------. 1986b. Quality Criteria for Water - 1986. EPA 440/5-86-001. Office of Water Regulations and Standards. Washington, DC.

U. S. Soil Conservation Service. 1983. Computer Program for Project Formulation Hydrology. Technical Release 20.

----------. 1991. The Wachusett Area Water Quality Protection Project.

Walker, W. W. 1990. P8 Urban Catchment Model Program Documentation Version 1.1. Prepared for IEP, Inc., Northboro, MA and Narragansett Bay Project, Providence, RI.

APPENDIX A

GATES BROOK STORMWATER STUDY

LABORATORY METHODS

TABLE A-1

GATES BROOK STORMWATER STUDY
SAMPLE PARAMETERS AND ANALYTICAL METHODS AT LES

PARAMETER	METHODS	REPORTED AS	LIMITS OF DETECTION	REFERENCE	HOLDING TIME
pH	Electrometric, glass indicator, silver chloride	pH logarithmic units	±0.1 Std. Units	EPA 1983, Method 150.1	Analyze immdiately
Total Alkalinity	0.02 N sulfuric acid potentiometric titration to pH 4.5. Orion Model 701 Digital pH Meter	mg/l $CaCO_3$	---	Standard Methods, 16th ed., part 403	14 days
Hardness	Hardness by calculation	mg/l equivalent	---	Standard Methods, 16th ed., part 314A	6 months
Suspended Solids	Filtration through standard glass fiber filter paper. Residue dried at 103-105 °C. Gravimetric.	mg/l SS	2.5 mg/l	Standard Methods, 16th ed., part 209C	7 days
Total Solids	Evaporation to dryness at 103-105 °C. Gravimetric.	mg/l TS	10 mg/l	Standard Methods, 16th ed., part 209A	7 days
Total Volatile Solids	Gravimeteric, Ignition at 550 °C	mg/l TVS	<10 mg/l	EPA 1983, Method 160.4	7 days
Turbidity	Nephelometry. Hach Turbidimeter Model 2100A	Nephelometric Turbidity Units	---	Standard Methods, 16th ed., part 214A	48 hours
Specific Conductivity (25 °C)	Wheatstone Bridge type meter. Yellow Springs Instrument conductivity bridge Model 31.	µmhos/cm	---	Standard Methods, 16th ed., part 205	28 days
Chloride	Argentometric (titration with silver nitrate)	mg/l Cl	1.0 mg/l	Standard Methods, 16th ed., part 407A	28 days

PARAMETER	METHODS	REPORTED AS	LIMITS OF DETECTION	REFERENCE	HOLDING TIME
Total Kjeldahl-Nitrogen	Acid digestion using Technicon BD-40 Block Digester. Colorimetric analysis (reaction of ammonia, sodium salicylate, and sodium hypochlorite in buffered alkaline medium) using Traacs 800 Auto Analyzer.	mg/l TKN	0.09 mg/l	EPA 1983, Method 351.2	28 days
Ammonia-Nitrogen	Colormetric, Automated Phenate using Traacs 800 Auto Analyzer	mg/l NH_3-N	0.02 mg/l	Standard Methods, 16th ed., part 417G	28 days
Nitrate-Nitrogen	Colorimetric, Automated hydrazine reduction	mg/l NO_3-N	0.05 mg/l	EPA 1983 Method 353.1	28 days
Total Phosphorus	Hot persulfate digestion. Ascorbic acid reduction. Manual spectophotometric using a 10 cm path length cell.	mg/l P	0.01 mg/l	Standard Methods, 16th ed., part 424C III and 424F.	28 days
Fecal Coliform	Membrane filter technique	Fecal coliform colonies/100 ml	<5 colonies	Standard Methods, 16th ed., part 908C	6 hours

TABLE A-2

GATES BROOK STORMWATER STUDY
SAMPLE PARAMETERS AND ANALYTICAL METHODS AT LYCOTT & REVET LABORATORIES

PARAMETER	METHODS	REPORTED AS	LIMITS OF DETECTION	REFERENCE	HOLDING TIME
pH	Electrometric, glass indicator, silver chloride	pH logarithmic units	±0.1 Std. Units	EPA 1983, Method 150.1	Analyze immdiately
Total Alkalinity	0.02 N sulfuric acid potentiometric titration to pH 4.5.	mg/l $CaCO_3$	1.0 mg/l	EPA 1983, Method 310.1	14 days
Suspended Solids	Filtration through standard glass fiber filter paper. Residue dried at 103-105 °C. Gravimetric.	mg/l SS	0.1 mg/l	EPA 1983, Method 160.2	7 days
Total Solids	Evaporation to dryness at 103-105 °C. Gravimetric.	mg/l TS	0.1 mg/l	EPA 1983, Method 160.3	7 days
Total Volatile Solids	Gravimeteric, Ignition at 550 °C	mg/l TVS	1.0 mg/l	EPA 1983, Method 160.4	7 days
Total Dissolved Solids	Gravimetric, Ignition at 180 °C	mg/l TDS		EPA 1983, Method 160.1	48 hours
Turbidity	Nephelometry. Hach Turbidimeter Model 2100A	Nephelometric Turbidity Units	0.1 NTU	EPA 1983, Method 180.1	48 hours
Total Kjeldahl-Nitrogen	Digestion and distillation, followed by titration, potentiometric	mg/l TKN	0.1 mg/l	EPA 1983, Method 351.1 or 351.4	28 days
Ammonia-Nitrogen	Electrode	mg/l NH_3-N	0.01 mg/l	EPA 1983, Method 350.3	28 days

PARAMETER	METHODS	REPORTED AS	LIMITS OF DETECTION	REFERENCE	HOLDING TIME
Nitrate-Nitrogen	Colorimetric, Automated hydrazine reduction	mg/l NO_3-N	0.1 mg/l	4500-NO3-D or EPA 1983, Method 353.1	28 days
Total Phosphorus	Persulfate digestion followed by ascorbic acid reduction.	mg/l P	0.005 mg/l	EPA 1983, Method 365.3 or 405.1	28 days

TABLE A-3

GATES BROOK STORMWATER STUDY

METALS SAMPLE PARAMETERS AND ANALYTICAL METHODS AT LES

PARAMETER	METHOD	REPORTED AS	LIMITS OF DETECTION (mg/l)	REFERENCE	MAXIMUM HOLDING TIME
Cadmium	AA Graphite Furnace	mg/l	0.001	EPA Method 213.2	6 months
Calcium	AA Flame	mg/l	0.2	EPA Method 215.1	6 months
Chromium	AA Graphite Furnace	mg/l	0.002	EPA Method 218.2	6 months
Copper	AA Graphite Furnace	mg/l	0.002	EPA Method 220.2	6 months
Iron	AA Flame	mg/l	0.04	EPA Method 236.2	6 months
Lead	AA Graphite Furnace	mg/l	0.002	EPA Method 239.2	6 months
Magnesium	AA Graphite Furnace	mg/l	0.02	EPA Method 239.2	6 months
Mercury	AA Graphite Furnace	mg/l	0.0002	EPA Method 245.2	6 months
Nickel	AA Graphite Furnace	mg/l	0.002	EPA Method 249.2	6 months
Zinc	AA Graphite Furnace	mg/l	0.02	EPA Method 289.2	6 months

TABLE A-4

GATES BROOK STORMWATER STUDY

Sample Collection & Preservation Methods[1]

Parameter	Container[2]	Processing & Storage
pH	—	Transport on ice to LES
Total Alkalinity	P/G	Cool 4 °C
Conductivity	P/G	Cool 4 °C
Total Hardness	P/G	HNO_3, pH ≤ 2, cool 4 °C
Total Solids	P/G	Cool 4 °C
Suspended Solids	P/G	Cool 4 °C
Chloride	P/G	Cool 4 °C
Total Kjeldahl-Nitrogen	P/G	H_2SO_4, pH ≤ 2, cool 4 °C
Ammonia-Nitrogen	P/G	H_2SO_4, pH ≤ 2, cool 4 °C
Nitrate-Nitrogen	P/G	H_2SO_4, pH ≤ 2, cool 4 °C
Total Phosphorus	P/G	H_2SO_4, pH ≤ 2, cool 4 °C
Bacteria	P/G	Cool 4 °C
Turbidity	P/G	Cool 4 °C

[1] Required containers, preservation techniques, and holding times, per Table II 40 CFR Part 136:
P/G - Polyethylene or glass

[2] The Isco® sampler bottles and laboratory transfer bottles were acid washed. Nutrient bottles were washed with a 1:1 solution of hydrochloric acid and rinsed three times with distilled/deionized water. Metals bottles were washed with a 1:1 solution of nitric acid, followed by three rinses with distilled/deionized water, another wash with 1:1 hydrochloric acid, and three more rinses with distilled/deionized water.

APPENDIX B

GATES BROOK STORMWATER STUDY

WATER QUALITY ANALYSIS DATA

APPENDIX B-1
GATES BROOK STORMWATER STUDY
PHYSICOCHEMICAL DATA (mg/l)

Date	Weather	Time	Ppn	pH	Alk	Hard	SS	TS	TVS	Turb	Cond	Cl	TKN	NH3-N	NO3-N	TP	Fecal Coliform	Notes
8/23/90	Dry			7.4	51	68	-1	232				90	0.25	-0.02	1.70			
10/15/90	"Dry"	0900			36	50	-1	180	54	1.0	297	56	0.70	0.04	0.99	0.037	260	
		1000			32	56	1	170	26	1.0	298	2	0.83	0.03	1.03	0.039	400	
		1100			32	50	2	180	48	1.0	302	57	0.48	-0.02	1.12	0.039	180	
		1200			32	50	-1	180	46	0.9	303	56	0.88	-0.02	1.32	0.043	300	
		1300			32	51	-1	180	74	1.0	304	2	0.94	-0.02	1.14	0.046	240	
			Max		36	56	2	180	74	1.0	304	57	0.94	0.04	1.32	0.046	400	
			Min		32	50	-1	170	26	0.9	297	2	0.48	-0.02	0.99	0.037	180	
			Mean		33	51	1	178	50	1.0	301	34	0.77	0.03	1.12	0.041	276	
																		MDC FC
10/23/90	Wet	1200		6.8	49	68	1	230	80	0.8	371	72	0.59	0.14	1.70	0.034	120	114
		1215		6.6	41	63	2	220	74	1.3	343	68	0.77	0.03	1.48	0.023	160	150
		1230		6.6	41	63	-1	210	56	1.2	345	69	0.52	0.20	1.48	0.023	150	156
		1245		6.6	41	60	-1	220	76	1.1	346	69	0.54	-0.02	1.54	0.033	120	164
		1300		6.6	40	61	2	220	54	1.1	344	71	0.29	-0.02	1.46	0.026	170	170
		1315		6.6	40	58	-1	220	64	1.2	337	65	0.43	-0.02	1.51	0.032	180	
		1330		6.6	39	61	2	210	54	1.3	331	66	0.32	-0.02	1.84	0.027	120	220
			Max	6.8	49	68	2	230	80	1.3	371	72	0.77	0.20	1.84	0.034	180	220
			Min	6.6	39	58	-1	210	54	0.8	331	65	0.29	-0.02	1.46	0.023	120	114
			Mean		42	62	1	219	65	1.1	345	69	0.49	0.06	1.57	0.028	146	162

NOTE: "-" denotes "<"

Date	Weather	Time	Ppn		Alk	Hard	SS	TS	TV	Turb	Cond	Cl	TKN	NH3-N	NO3-N	TP	Fecal Coliform	Notes
12/04/90	Wet	0000		6.8	45	65	1	240	36		434	74	0.24	0.09	1.82	0.021		
		0130		6.6	45	74	1	232	48		436	77	0.49	0.07	1.90	0.016		
		0300		6.6	47	69	1	244	44		454	62	0.54	0.08	1.10	0.022		
		0430				53							0.76	0.23	1.40	0.053		
		0600		6.5	37	60	39	204	40		367	62	0.31	0.09	1.80	0.026		
		0730		6.3	21	42	222	354	44		208	57	1.00	0.23	1.10	1.000		
		0900		6.2	13	29	300	308	152		120	22	1.60	0.12	0.95	0.600		
		1030		6.3	13	24	80	142	42		115	17	0.80	0.12	0.70	2.100		
		1100		6.2	14	20	64	126	50		114	19	2.80	0.10	0.66	0.300		
		1230		6.2	14	21	52	132	52		119	20	1.90	0.12	0.71	0.170		
		1400		6.2	17	22	35	128	50		140	23	0.80	0.10	0.82	0.140		
		1530		6.2	18	22	23	124	44		154	26	9.30	0.05	1.04	0.120		
			Max	6.8	47	74	300	354	152		454	77	9.30	0.23	1.90	2.100		
			Min	6.2	13	20	1	124	36		114	17	0.24	0.05	0.66	0.016		
			Mean		26	42	74	203	55		242	42	1.71	0.12	1.17	0.381		
12/18/90	Wet	0300		6.6	38	52	2	200	54		345	63	1.30	0.10	1.54	0.019		
		0500		6.4	36	65	3	196	44		354	63	0.80	0.13	1.68	0.017		
		0700		6.4	36	66	2	208	50		364	63	0.46	0.10	2.80	0.013		
		0900		6.4	36	57	2	204	44		374	67	0.16	-0.02	1.90	0.019		
		1100		6.4	35	55	3	208	48		355	62	0.86	0.11	1.80	0.027		
			Max	6.6	38	66	3	208	54		374	67	1.30	0.13	2.80	0.027		
			Min	6.4	35	52	2	196	44		345	62	0.16	-0.02	1.54	0.013		
			Mean		36	59	2	203	48		358	64	0.72	0.09	1.94	0.019		

Date	Weather	Time	Ppn		Alk	Hard	SS	TS	TV	Turb	Cond	Cl	TKN	NH3-N	NO3-N	TP	Fecal Coliform	Notes
01/16/91	Wet	1000	0.01															
		1100	0.02															
		1200	0.06															
		1218																
		1300	0.03														36	
		1335	0	6.6	43	61	2	800	14	0.9	1330	470	0.35	0.15	0.45	0.024	240	(1)
		1400	T	6.4	37	66	4	800	28	0.4	1340	410	1.30	0.24	0.25	0.042	38	
		1410	0	6.5	37	67	6	786	56	0.6	1270	390	0.18	0.08	1.30	0.025	62	
		1420	0	6.5	37	65	6	730	56	0.5	1240	360	0.06	0.06	2.10	0.041	48	
		1430	0	6.5	38	65	5	946	66	0.7	1240	360	0.50	0.10	2.20	0.054	218	(2)
		1445	0	6.5	37	62	8	708	72	0.7	1140	340	0.50	0.08	1.30	0.058	76	
		1500	0.03	6.5	37	57	5	694	70	0.6	1130	340	0.06	0.06	2.40	0.070	46	
		1515	0	6.5	37	65	8	720	106	0.7	1170	350	0.16	0.16	1.00	0.042	58	
		1530	0	6.6	36	69	11	748	84	0.7	1260	360	0.63	0.10	2.20	0.057	76	
		1545	0	6.5	36	69	9	856	72	1.2	1390	410	0.43	0.13	2.20	0.064	60	
		1600	0.02	6.6	35	76	17	972	76	0.8	1640	440	0.32	0.10	2.60	0.064	92	
		1630	0	6.5	33	81	25	1176	94	1.1	1950	340	0.74	0.18	2.20	0.081		
		1700	0.1	6.5	33	79	26	1020	234	0.7	1720	530	1.10	0.25	2.00	0.110		
		1730	0	6.5	33	74	60	1096	134	0.3	1750	530	0.75	0.17	1.80	0.170		
		1800	0.04	6.4	28	89	25	974	88	1.5	1560	340	1.20	0.18	2.00	0.290		
		1900	0.08	6.1	19	57	47	726	68	0.8	1160	340	1.00	0.27	1.80	0.230		
		2000	T	6.4	28	50	70	614	76	1.4	980	280	0.69	0.23	1.80	0.210		
		2100	0.18	6.4	28	52	76	406	40	0.4	728	190	0.93	0.12	1.80	0.061		
01/17/91		1200															164	
		Total ppn	0.57															
			Max	6.6	43	89	76	1176	234	1.5	1950	530	1.30	0.27	2.60	0.290	240	
			Min	6.1	19	50	2	406	14	0.3	728	190	0.06	0.06	0.25	0.024	36	
			Mean		34	67	23	821	80	0.8	1333	377	0.61	0.15	1.74	0.094	93	

(1) 15 large colonies, remainder small

(2) 27 large colonies, remainder small

Date	Weather	Time	Ppn		Alk	Hard	SS	TS	TV	Turb	Cond	Cl	TKN	NH3-N	NO3-N	TP	Fecal Coliform	Notes
02/04/91	snow melt	1330		6.6	39	46	7	222	58	0.6	368	73	0.06	0.06	-0.02	0.044		
	& dry	1430		6.7	34	59	10	224	54	0.3	365	74	0.54	0.09	2.40	0.035		
		1730		6.6	30	41	21	200	58	0.3	316	62	0.32	0.10	2.00	0.069		
		2030		6.6	32	45	10	204	70	0.3	326	64	0.20	0.06	2.00	0.043		
		2330		6.6	33	51	6	206	54	0.0	339	68	0.23	0.06	2.00	0.027		
02/05/91		0230		6.6	33	49	5	218	56	0.4	353	70	0.24	0.12	2.00	0.025		
		0530		6.7	35	51	5	212	56	0.4	357	70	0.27	0.02	2.00	0.024		
		0830		6.5	30	58	3	220	80	0.4	364	74	0.54	0.37	2.60	0.018		
		1130		3.2			1	286	114	0.6	715	71						
			Max	6.7	39	59	21	286	114	0.6	715	74	0.54	0.37	2.60	0.069		
			Min'	3.2	30	41	1	200	54	0.0	316	62	0.06	0.02	-0.02	0.018		
			Mean		33	50	7	221	67	0.4	389	70	0.30	0.11	1.88	0.036		

Date	Weather	Time	Ppn		Alk	Hard	SS	TS	TV	Turb	Cond	Cl	TKN	NH3-N	NO3-N	TP	Fecal Coliform	Notes
02/07/91		0100	0.02															
		0200	T															
		0300	0.04															
		0500	0.03															
		0500	0.03															
		0600	0.02															
		0700	0.02															
		0800	0.04															
		0900	0.02															
		1000	0.03															
		1100	0.05															
		1130															130	
		1200	0.07															
		1300	0.09															
		1400	0.07	6.5	24	41	78	232	56	9.3	269	55	0.57	0.23	1.50	0.220	220	
		1500															720	
		1600	0.10	6.4	21	30	78	202	52	14.0	224	45	0.87	0.12	1.30	0.270		
		1800	0.03	6.5	25	38	27	170	42	7.0	256	52	0.70	0.33	2.30	0.120		
		2000	0.04	6.6	26	36	20	174	44	6.4	274	55	0.28	0.07	1.40	0.100		
		2200	0.01	6.6	28	41	13	182	48	3.2	296	60	0.28	0.04	1.60	0.063		
		2400	T	6.6	28	48	7	196	50	3.1	317	65	0.13	0.03	1.70	0.054		
02/08/91		0200	T	6.6	29	45	8	204	50	2.1	328	68	0.56	0.08	1.80	0.045		
		0400		6.6	30	49	6	206	52	2.5	331	69	0.40	0.05	1.80	0.037		
		0600		6.3	21	42	7	222	60	2.1	338	77	0.36	0.05	1.70	0.031		
		0800		6.6	29	45	1	214	52	1.9	303	70	0.25	-0.02	1.70	0.033		
		1000		6.5	27	49	3	212	54	1.1	334	70	0.26	0.08	1.80	0.029		
		1200		6.4	19	48	2	220	60	1.0	334	75	0.27	-0.02	1.70	0.025		
		Total Ppn	0.72															
			Max	6.6	30	49	78	232	60	14.0	338	77	0.87	0.33	2.30	0.270		
			Min	6.3	19	30	1	170	42	1.0	224	45	0.13	-0.02	1.30	0.025		
			Mean		26	43	21	203	52	4.5	300	63	0.41	0.09	1.69	0.086		

Date	Weather	Time	Ppn		Alk	Hard	SS	TS	TV	Turb	Cond	Cl	TKN	NH3-N	NO3-N	TP	Fecal Coliform	Notes
04/30/91	Wet	0530	0.01															
	2-hr	0730	0.04															
		0810															110	
		0830															360	
		0850															300	
		0910															300	
	Comp	0930	0.13														700	
		1000															600	
		1030															2700	
		1100															800	
		1130	0.63	7.0	33	28	87	210	86	4.0	216	54	1.60	0.15	1.00	0.210		
		1200															1000	
		1400															1400	
		1330	0.67	7.0	14	17	346	398	64	6.0	115	20	2.50	0.08	0.68	0.620		
		1530	0.11	7.1	17	20	60	172	64	4.0	147	24	1.40	0.16	0.82	0.183		
		1730	0.03	7.2	21	24	35	162	72	3.0	193	35	0.87	0.17	0.92	0.099		
		1930	0.05	7.2	23	28	17	172	48	2.3	229	38	0.91	0.07	1.00	0.078		
		2130	T	7.1	26	30	17	186	44	2.1	262	49	0.71	0.05	1.10	0.069		
		2330	T	7.1	27	32	13	188	50	2.0	272	52	0.66	0.13	1.30	0.056		
05/01/91		0130	T	6.9	14	17	206	222	64	6.6	111	18	1.60	0.07	0.69	0.340		
		0330	T	7.1	28	31	26	184	50	1.6	268	50	0.60	0.11	1.20	0.046		
		0530	T	7.1	28	32	11	184	52	2.0	270	51	0.90	0.24	1.10	0.046		
		0730	T	7.1	29	32	9	188	58	1.2	274	51	0.53	0.37	1.30	0.043		
		0930	T	7.1	30	32	4	178	60	1.1	280	54	0.69	0.17	1.30	0.038		
		1130		7.1	30	40	4	400	64	0.4	269	52	0.66	0.05	1.20	0.046		
		1330		7.2	30	39	4	182	38	0.5	270	54	0.74	0.09	1.20	0.034		
		1400															4100	
		1530		7.1	31	40	4	190	46	0.5	275	53	0.49	0.40	1.20	0.038		
		1600															3000	
		1730		7.1	30	42	5	188	48	0.4	279	53	0.72	-0.02	1.30	0.032		
		1930		7.1	30	43	4	194	56	0.4	281	53	0.32	-0.02	1.40	0.033		
		2130		7.1	32	56	4	196	52	0.6	285	55	0.36	0.03	1.30	0.045		
			Max	7.2	33	56	346	400	86	6.6	285	55	2.50	0.40	1.40	0.620	4100	
			Min	6.9	14	17	4	162	38	0.4	111	18	0.32	-0.02	0.68	0.032	110	
			Mean		26	32	47	211	56	2.2	239	45	0.90	0.13	1.11	0.114	1281	

Total rainfall for storm = 1.69

Date	Weather	Time	Ppn		Alk	Hard	SS	TS	TV	Turb	Cond	Cl	TKN	NH3-N	NO3-N	TP	Fecal Coliform	Notes
05/21/91	Dry	0600		7.6	37	50	3	226	54	1.1	351	71	0.68	0.04	1.80	0.027		
	6-hr	1200		7.5	39	50	3	248	36	0.7	348	73	0.84	0.03	1.80	0.012		
05/22/91	comp	0600		7.6	39	52	2	234	56	0.5	345	71	0.78	-0.02	1.90	0.010		
		1200		6.8	25	47	-1	236	56	0.4	355	73	0.50	0.06	2.80	0.013		
			Mean		35	50	2	236	51	0.7	350	72	0.70	0.04	2.08	0.016		
05/30/91	Wet	1600	T															
	2-hr	1800	0.13	7.5	45	48	2	232	62	0.6	294	74	0.42	-0.02	1.80	0.014		
	comp	2000	0.53	7.4	32	38	63	244	68	0.4	366	58	1.80	0.03	1.70	0.200		
		2200	0.02	7.2	21	27	26	144	56	1.0	172	31	1.20	0.32	2.40	0.110		
		2400	0	7.3	30	37	5	168	56	0.9	251	45	0.63	-0.02	1.40	0.040		
05/31/91		0200	0	7.6	38	44	4	282	76	0.7	312	60	0.42	-0.02	1.00	0.033		
		0400	0	7.7	40	47	3	238	52	0.6	325	70	0.73	-0.02	1.60	0.025		
		0600	0	7.6	41	60	3	104	54	0.7	331	69	0.69	0.06	1.70	0.028		
		0800	0	7.6	41	49	2	256	48	0.6	335	70	0.52	-0.02	1.70	0.014		
			Max	7.7	45	60	63	282	76	1.0	366	74	1.80	0.32	2.40	0.200		
			Min	7.2	21	27	2	104	48	0.4	172	31	0.42	-0.02	1.00	0.014		
			Mean		35	44	17	205	60	0.7	292	58	0.86	0.08	1.67	0.068		

Total rainfall for storm = 0.68 in

Date	Weather	Time	Ppn	pH	Alk	Hard	SS	TS	TVS	Turb	Cond	Cl	TKN	NH3-N	NO3-N	TP	Coliform	Notes
06/05/91	Wet	1200		7.3	42	6	2	234	60	0.2	388	72	1.80	0.10	1.90	0.018	145	(1)
06/11/91	Wet	0900	T															
		1800		7.5	44	56	-1	238	34	0.4	404	76	1.10	-0.02	2.20	0.017		
		1900		7.5	42	57	10	244	62	0.5	388	72	1.10	0.05	2.10	0.036		
		1930																
		2000	0.06	6.9	29	45	226	386	136	3.8	278	49	2.70	0.20	1.80	0.570		
		2030																
		2100	T	6.9	24	37	110	254	94	4.2	246	43	1.80	0.33	1.70	0.330		
		2130																
		2200		7.0	24	40	34	172	54	4.3	234	41	1.10	0.30	1.60	0.150		
		2230																
		2300		7.3	26	39	15	158	48	2.9	246	38	0.93	0.24	1.70	0.082		
		2330																
		2400		7.1	30	47	8	160	40	2.3	262	42	0.60	0.15	1.60	0.047		
6/12/91		0100		7.2	32	41	7	168	36	1.6	289	51	0.45	0.14	1.90	0.064		
		0200		7.3	36	52	5	192	52	0.9	338	61	0.18	0.02	1.70	0.074		
		0300		7.5	40	49	3	218	58	0.6	364	63	0.88	0.05	2.20	0.042		
			Max	7.5	44	57	226	386	136	4.3	404	76	2.70	0.33	2.20	0.570		
			Min	6.9	24	37	-1	158	34	0.4	234	38	0.18	-0.02	1.60	0.017		
			Mean		33	46	42	219	61	2.2	305	54	1.08	0.15	1.85	0.141		

Total rainfall for storm = 0.06 in

Date	Weather	Time	Ppn	pH	Alk	Hard	SS	TS	TV	Turb	Cond	Cl	TKN	NH3-N	NO3-N	TP	Fecal Fecal Coliform	Notes
06/12/91	Wet	1545															332	
		1545-1645		7.6	40	2	160	200	-1	1.8	350	73	0.13	0.04	1.70	0.102		
		1615															7400	
		1645															1700	
		1645																
		1700-1715		7.4	30	41	114	256	-1	25.0	220	43	0.26	-0.01	1.60	0.291		
		1645		7.6	39		51	290	2	4.4	380		0.15	-0.01	1.80	0.037		
		1700		7.3	26	37	97	246	26	8.2	192	35	0.21	0.01	1.60	0.220		
		1715		7.3	28	45	107	286	23	25.0	250	47	0.27	-0.01	1.50	0.065	11700	
		1730		7.3	40	39	82	296	1	240.0	220	43	0.26	-0.01	1.10	0.271		
		1730-1745		7.2	19	33	44	160	-1	16.0	200	34	0.24	0.14	1.10	0.066		
		1745															9000	
		1800-1815		7.3	24	39	75	256	40	22.0	220	43	0.19	-0.01	1.20	0.167		
		1815															7700	
		1830		7.3	21		28	312	61	14.0	190		0.11	-0.01	1.20	-0.005		
		1845															12800	
		1900-1945		7.3	22	34	14	80	-1	4.8	200	33	0.19	0.13	1.20	0.009		
		1945															5430	
		2045															4270	
06/13/91		930															140	
			Max	7.6	40	45	160	312	61	240.0	380	73	0.27	0.14	1.80	0.291	12800	
			Min	7.2	19	2	14	80	-1	1.8	190	33	0.11	-0.01	1.10	-0.005	332	
			Mean		29	33	77	238	15	36.1	242	44	0.20	0.04	1.40	0.123	6704	

Total rainfall for storm = 0.48 in

Notes:

(1) After 3 days light rain

(2) FC in last page

Date	Weather	Time	Ppn	pH	Alk	Hard	SS	TS	TV	Turb	Cond	Cl	TKN	NH3-N	NO3-N	TP	Fecal Coliform	Notes
06/19/91	Wet	1400	0.42	6.6	34		7	266	2	0.7			0.83	0.51	1.25	-0.005	120	
		1410															80	
		1415																
		1430		7.2	42		7	276	-1	1.1			0.56	0.49	1.60	0.005		
		1445		7.3	40		17	294	-1	3.3			0.16	-0.01	1.75	-0.005	500	
		1500	0.11	7.3	40		40	284	2	6.9			0.16	0.09	1.75	0.156	2500	
		1510		7.3	22		72	268	1	11.7			0.18	0.09	1.10	0.268	3900	
		1515																
		1530		7.2	30		59	262	-1	7.2			0.82	0.65	1.25	0.241	3200	
		1545		7.2	30		28	248	2	13.1			0.38	0.28	1.30	-0.005	6600	
		1600	0.02	7.2	30		27	250	3	6.3			0.75	0.66	1.90	0.008	9600	
		1615		7.2	28		17	232	2	4.5			0.89	0.80	1.00	0.137	7500	
		1630																
		1645																
		1700	T															
		1715																
		1730																
		1745																
		1800	T															
		1815																
		1830																
		1845																
		1900		7.2	28		22	180	3	2.7			0.39	0.34	1.10	-0.005	1-hr comp	
		2100		7.3	36		15	276	1	1.4			0.82	0.60	1.30	-0.005	1-hr comp	
		2300		7.2	38		11	224	-1	1.0			0.30	0.21	1.25	-0.005	1-hr comp	
6/20/91		0100		7.4	42		2	242	2	0.8			0.18	0.14	1.40	-0.005	1-hr comp	
		1400																
		0000																
			Max	7.4	42		72	294	3	13.1			0.89	0.80	1.90	0.268	9600	
			Min	6.6	22		2	180	-1	0.7			0.16	-0.01	1.00	-0.005	80	
			Mean		34		25	254	1	4.7			0.49	0.37	1.38	0.065	3778	

Total rainfall for storm = 0.55 in

Date	Weather	Time	Ppn	pH	Alk	Hard	SS	TS	TV	Turb	Cond	Cl	TKN	NH3-N	NO3-N	TP	Fecal Coliform	Notes
06/25/91	Dry			7.5	45	60	2	238	30	0.5	394	66	0.51	0.06	2.60	0.020		
07/23/91	Wet	0600		6.6	49	70	9	238	26	0.7	390	76	0.71	0.10	2.50	0.040		
		0615																
		0630				45	42	250	56	3.0	347	66	1.40	0.26	2.00	0.120		
		0645		6.3	28	37	16	190	60	3.6	248	75	1.60	0.35	1.90	0.140	30000	
		0700		6.2	21	31	26	148	44	3.7	184	31	1.10	0.56	1.50	0.160	6000	
		0715		6.2	19	24	28	128	32	3.0	166	28	0.91	0.61	2.30	0.130		
		0730		6.2	20	36	17	124	26	3.6	169	32	0.74	0.24	1.50	0.130	4000	
		0745		6.4	31	49	11	180	30	2.4	277	63	0.87	0.27	1.70	0.090	3000	
		0800																
		0815		6.5	40	69	6	242	68	2.0	351	71	1.00	0.23	2.70	0.070	7000	
		0830																
		0845		6.5	38	69	7	226	58	2.2	340	69	0.91	0.32	2.00	0.060	6000	
		0900																
		0915		6.6	38	62	6	432	60	2.1	350	66	0.94	0.17	2.40	0.050	8000	
			Max	6.6	49	70	42	432	68	3.7	390	76	1.60	0.61	2.70	0.160	30000	
			Min	6.2	19	24	6	124	26	0.7	166	28	0.71	0.10	1.50	0.040	3000	
			Mean		32	49	17	216	46	2.6	282	58	1.02	0.31	2.05	0.099	9143	

Date	Weather	Time	Ppn	pH	Alk	Hard	SS	TS	TV	Turb	Cond	Cl	TKN	NH3-N	NO3-N	TP	Fecal Coliform	Notes
08/19/91	Wet	1045					18	166		3.4	90		2.30	0.02	0.41	0.650		
		1245					114	180		4.4	74		1.40	-0.02	0.35	0.380		
	comp	1445					162	298		6.3	62		1.50	-0.02	0.31	0.310		
		1645					265	404		13.0	53		1.60	0.02	0.38	0.860		
		1845					198	198		7.1	83		1.00	-0.02	0.56	0.350		
		2045					94	150		5.1	115		0.82	0.04	0.77	0.230		
		2245					60	3112		4.2	153		0.76	-0.02	0.65	0.200		
08/20/91		0045					21	144		4.1	169		0.58	-0.02	0.60	0.100		
		0245					29	132		4.5	180		0.68	0.06	0.72	0.110		
		0445					14	136		4.7	183		0.64	0.02	0.56	0.090		
		0645					10	140		4.0	197		0.61	0.15	0.85	0.090		
		0845					5.5	126		3.2	203		0.54	0.03	0.70	0.080		
			Max				265	3112		13	203		2.3	0.15	0.85	0.86		
			Min				5.5	126		3.2	53		0.54	-0.02	0.31	0.08		
			Mean				83	432		5	130		1.04	0.04	0.57	0.29		

Date	Weather	Time	Ppn	pH	Alk	Hard	SS	TS	TV	Turb	Cond	Cl	TKN	NH3-N	NO3-N	TP	Fecal Coliform	Notes
09/19/91	Wet	1100				54							0.72	0.11	2.00	-0.030		
		1200				50							0.70	0.08	1.90	0.050	1800	
These		1300		6.8	47	43	18	244	52	1.4	326	70	1.20	0.09	1.80	0.070	3980	
times		1230				51							1.20	0.22	2.00	0.180		
need		1230		6.8	49	39	70	322	92	0.7	371	79	0.46	0.07	1.60	0.060		
to be		1330															5300	
checked.		1400		6.8	35	47	11	200	64	1.4	266	53	0.38	0.10	2.30	-0.030	3620	
		1500		2.7		44	6	476	273	1.2	1145	183	0.37	-0.02	1.90	-0.030		*Possible
		1515															3120	contamin
		1600		6.8	43	44	2	232	64	0.8	323	66	0.61	-0.02	1.80	-0.030		with H2S
		1700		6.5	30	44	2	230	58	0.8	326	64	0.28	0.02	1.80	-0.030		
		1800		6.9	42	44	3	230	54	0.8	312	61	0.17	-0.02	1.70	-0.030		
		1900		6.9	42	39	2	224	58	0.7	295	60	0.35	0.02	1.80	-0.030		
		2000		6.9	41	44	7	198	54	0.7	293	57	0.23	-0.02	1.90	-0.030		
		2100		6.9	41	44	1	226	56	0.6	306	63	0.29	0.17	1.60	-0.030		
		2200		6.9	43		5	306	72	0.9	346	72						
09/20/91		0000				33							0.94	0.03	1.40	0.250		
		0100		6.4	18	29	18	210	72	4.2	240	53	0.77	0.02	1.20	0.100		
		0100		6.7	27	25	14	152	32	3.4	204	44	0.47	0.03	1.00	0.060		
		0200		6.7	23	26	10	126	40	4.9	173	32	0.56	0.02	0.94	0.110		
		0300		6.6	21		2	138	46	3.2	168	71						
		0730															8500	
		0800															8500	
		0830															12700	
		0900															18500	
		0945																
		1045															16200	
		1145															14700	
		1315															10500	
		1410															TNTC	
		1500															TNTC	
			Max	6.9	49	51	70	476	273	4.9	1145	183	1.2	0.22	2.3	0.250	18500	
			Min	2.7	18	25	1	126	32	0.6	168	32	0.17	-0.02	0.94	-0.030	1800	
			Mean		36	40	11	234	72	1.7	340	69	0.55	0.06	1.65	0.071	8952	

Date	Weather	Time	Ppn	pH	Alk	Hard	SS	TS	TV	Turb	Cond	Cl	TKN	NH3-N	NO3-N	TP	Fecal Coliform	Notes
09/25/91	Wet	0045					-1	229					0.28		1.8	0.2		
		0145	0.03				-1	227					0.08		1.7	0.21		
		0245	0.02				-1	227					0.54		1.7	0.21		
		0345	0.2				4.1	224					0.84		1.6	0.22		
		0445	0.25				78	226					3.14		1.2	0.52		
		0545	0.27				133	203					2.37		0.61	0.66		
		0645	0.38				36	99					1.35		0.49	0.43		
		0730															8500	
		0745	0.29				27	195					0.5		0.44	0.37		
		0800															8500	
		0830															12700	
		0845	0.15				34	108					0.84		0.44	0.4		
		0900															18500	
		0945	0.26				24	106					1.09		0.53	0.33		
		1045	0.64				56	244					2.86		0.47	0.51	16200	
		1145	0.48				50	110					1.77		0.39	0.64	14700	
		1245	0.01				*	*					1.59		0.44	0.43		*Sample
		1315															10500	lost
		1410															TNTC	by lab
		1445	T				*	*					1.47		0.64	0.37		
		1500															TNTC	
		1645	T				*	*					1.35		0.71	0.29		
		1845	T				*	*					1.06		0.67	0.300		
		2045	0.02				*	*					1.39		0.68	0.270		
			Max				133	244					3.14		1.8	0.66	18500	
			Min				-1	99					0.08		0.39	0.20	8500	
			Mean				37	183					1.32		0.85	0.37	12800	

Date	Weather	Time	Ppn	pH	Alk	Hard	SS	TS	TV	Turb	Cond	Cl	TKN	NH3-N	NO3-N	TP	Fecal Coliform	Notes
10/15/91	Wet	1845				88	-1	252					0.3	-0.02	1.8	0.014		
		1945				89	-1	242					0.27	-0.02	1.8	0.007		
		2045				88	-1	242					0.58	0.03	2	0.01		
		2145				86	-1	268					0.9	-0.02	1.9	0.013		
		2245				95	-1	244					0.26	-0.02	1.8	0.013		
		2345				94	-1	240					0.41	-0.02	2	0.019		
10/16/91		0045				86	1	224					0.31	-0.02	1.9	0.028		
		0145				78	1.5	156					0.44	0.03	1.6	0.023		
		0245				73	-1	196					0.66	0.03	1.5	0.021		
		0345				78	-1	190					0.3	-0.02	1.5	0.02		
		0445				67	-1	190					0.44	-0.02	2	0.017		
		0545				62	-1	204					0.25	-0.02	1.5	0.012		
		0615															210	
		0645															120	
		0715															180	
		0745															120	
		0815															40	
		0900															70	
		0930															140	
		1000															80	
		1030															70	
		1100															40	
				Max		95	1.5	268					0.9	0.03	2.0	0.028	210	
				Min		62	-1	156					0.25	-0.02	1.5	0.007	40	
				Mean		82	1	221					0.43	0.02	1.8	0.016	107	

APPENDIX B-2
GATES BROOK STORMWATER STUDY
METALS DATA (MG/L)

Date	Weather	Time	Ppn	Fe	Mn	Ca	Al	Cu	Zn	Pb	Cr	Cd	Ni	As	Hg
8/23/90	Dry			0.05	0.04			0.009	0.014	-0.002	-0.001	-0.001	0.003	-0.001	-0.0002
10/15/90	"Dry"	0900		0.28	0.03	16	-0.050	0.008	0.02	-0.002	-0.001	-0.001	-0.002	0.004	-0.0002
		1000		0.28	0.02	18	0.056	0.019	-0.02	-0.002	-0.001	-0.001	-0.002	0.003	-0.0002
		1100		0.25	0.02	16	0.064	0.012	0.03	-0.002	-0.001	-0.001	-0.002	0.003	-0.0002
		1200		0.25	0.03	16	-0.050	0.003	0.02	-0.002	-0.001	-0.001	-0.002	0.003	-0.0002
		1300		0.23	0.02	16	0.091	0.004	0.18	-0.002	-0.001	0.020	-0.002	0.004	-0.0002
			Max	0.28	0.03	18	0.091	0.019	0.18	0.002	0.001	0.020	0.002	0.004	0.0002
			Min	0.23	0.02	16	-0.050	0.003	-0.02	-0.002	-0.001	-0.001	-0.002	0.003	-0.0002
			Mean	0.26	0.02	16	0.062	0.009	0.05	0.002	0.001	0.005	0.002	0.003	0.0002
10/23/90	Wet	1200		0.08	0.02	23	-0.050	0.003	0.02	-0.001	-0.001	-0.001	-0.002	0.001	-0.0002
		1215		0.15	0.04	23	0.056	0.007	0.08	-0.001	-0.001	-0.001	0.003	0.002	-0.0002
		1230		0.11	0.03	23	0.056	0.005	0.05	-0.001	-0.001	-0.001	-0.002	0.002	-0.0002
		1245		0.14	0.04	23	-0.050	0.002	0.02	-0.001	-0.001	-0.001	-0.002	0.003	-0.0002
		1300		0.09	0.03	21	0.053	0.003	0.03	-0.001	-0.001	0.003	-0.002	0.002	-0.0002
		1315		0.14	0.02	20	0.055	0.006	0.05	-0.001	-0.001	0.003	0.002	0.002	-0.0002
		1330		0.12	0.02	22	-0.050	0.003	0.02	-0.001	-0.001	-0.001	-0.002	0.002	-0.0002
			Max	0.15	0.04	23	0.056	0.007	0.08	0.001	0.001	0.003	0.003	0.003	0.0002
			Min	0.08	0.02	20	-0.050	0.002	0.02	-0.001	-0.001	-0.001	-0.002	0.001	-0.0002
			Mean	0.12	0.03	22	0.053	0.004	0.04	0.001	0.001	0.002	0.002	0.002	0.0002

Date	Weather	Time	Ppn	Fe	Mn	Ca	Al	Cu	Zn	Pb	Cr	Cd	Ni	As	Hg
12/04/90	Wet	0000		-0.05	0.018	20	-0.05	0.005	0.045	-0.002	0.004	-0.002	0.004	0.002	0.0004
		0130		-0.05	0.025	24	0.08	-0.002	0.053	-0.002	-0.002	0.005	0.012	0.001	-0.0002
		0300		-0.05	0.015	22	-0.05	0.005	0.030	-0.002	0.005	-0.002	0.003	-0.001	-0.0002
		0430		0.49	0.130	15	0.15	-0.002	0.064	0.003	0.004	0.002	0.003	0.001	-0.0002
		0600		0.30	0.090	19	0.10	-0.002	0.033	-0.002	0.005	-0.002	0.003	0.002	-0.0002
		0730		3.30	1.300	13	1.50	0.007	0.130	0.029	0.009	0.009	0.008	0.014	-0.0002
		0900		3.50	0.850	8.3	1.80	0.009	0.082	0.060	0.009	-0.002	0.014	0.013	-0.0002
		1030		1.90	0.290	7.2	1.30	-0.002	0.051	0.015	0.010	0.005	0.008	0.007	-0.0002
		1100		2.20	0.110	5	1.20	0.010	0.039	0.013	0.063	-0.002	0.008	0.007	-0.0002
		1230		1.60	0.110	5	0.88	-0.002	0.051	0.013	0.013	-0.002	0.006	0.005	-0.0002
		1400		1.30	0.370	6	0.78	-0.002	0.084	0.008	0.005	-0.002	0.007	0.004	-0.0002
		1530		1.00	0.290	6	0.71	-0.002	0.200	0.006	0.004	0.008	0.003	0.004	-0.0002
			Max	3.5	1.300	24	1.80	0.010	0.2	0.060	0.063	0.009	0.014	0.014	0.0004
			Min	-0.05	0.015	5	-0.05	-0.002	0.03	-0.002	-0.002	-0.002	0.003	-0.001	-0.0002
			Mean	1.31	0.300	13	0.72	0.004	0.072	0.013	0.011	0.004	0.007	0.005	0.0002

12/18/90 no metals data

Date	Weather	Time	Ppn	Fe	Mn	Ca	Al	Cu	Zn	Pb	Cr	Cd	Ni	As	Hg
01/16/91	Wet	1000	0.01												
		1100	0.02												
		1200	0.06												
		1300	0.03												
		1335		1.4	0.18	25	0.73	-0.002	0.046	0.008	-0.001	-0.001	0.003	0.002	-0.0002
		1400	T	2.9	0.40	23	1.5	-0.002	0.071	0.016	0.003	-0.001	0.003	0.008	-0.0002
		1410		3.3	0.35	29	1.7	0.011	0.120	0.022	0.003	0.001	0.019	0.007	0.0003
		1420		2.7	0.32	18	1.4	0.011	0.118	0.018	0.002	-0.001	0.006	0.007	-0.0002
		1430		0.50	0.12	21	0.25	-0.002	0.064	0.004	0.003	-0.001	-0.002	-0.001	0.0003
		1445		0.67	0.14	21	0.33	0.004	0.076	0.006	-0.001	-0.001	0.017	0.002	-0.0002
		1500	0.03	0.84	0.15	24	0.42	0.041	0.087	0.005	0.002	-0.001	0.130	0.002	-0.0002
		1515		1.1	0.18	26	0.59	-0.002	0.091	0.008	0.002	-0.001	-0.002	0.002	-0.0002
		1530		0.35	0.11	21	0.20	0.028	0.067	0.004	-0.001	-0.001	-0.002	0.001	-0.0002
		1545		0.33	0.10	20	0.26	0.006	0.025	0.002	-0.001	-0.001	0.004	0.002	-0.0002
		1600	0.02	0.29	0.09	18	0.13	0.014	0.037	-0.002	-0.001	-0.001	0.004	-0.001	-0.0002
		1630		0.42	0.11	21	0.26	-0.002	0.034	0.002	-0.001	0.005	-0.002	0.001	0.0003
		1700	0.1	0.30	0.10	18	0.16	0.018	0.070	0.003	-0.001	-0.001	0.020	-0.001	-0.0002
		1730		0.20	0.09	20	0.15	0.004	0.035	-0.002	0.002	0.004	-0.002	-0.001	-0.0002
		1800	0.04	0.16	0.08	22	0.10	-0.002	0.113	0.002	-0.001	-0.001	0.005	-0.001	-0.0002
		1900	0.08	0.38	0.11	21	0.27	-0.002	0.090	0.003	-0.001	-0.001	-0.002	0.002	-0.0002
		2000	T	3.4	0.34	15	1.8	0.022	0.079	0.023	0.008	0.005	0.020	0.01	0.0003
		2100	0.18	0.58	0.12	16	0.30	-0.002	0.028	-0.002	-0.001	-0.001	-0.002	0.002	0.0003
		Total ppt 0.57													
			Max	3.4	0.4	29	1.8	0.041	0.120	0.023	0.008	0.005	0.130	0.010	0.0003
			Min	0.16	0.08	15	0.1	-0.002	0.025	-0.002	-0.001	-0.001	-0.002	-0.001	-0.0002
			Mean	1.10	0.17	21	0.59	0.010	0.070	0.007	0.002	0.002	0.014	0.003	0.0002

Date	Weather	Time	Ppn	Fe	Mn	Ca	Al	Cu	Zn	Pb	Cr	Cd	Ni	As	Hg
02/04/91	snow me	1330		0.37	0.11	14	0.17	0.003	0.024	-0.002	-0.001	0.007	-0.002	0.002	-0.0002
	& dry	1430		0.32	0.11	19	0.14	0.004	0.007	-0.002	-0.001	-0.001	-0.002	0.002	-0.0018
		1730		0.56	0.13	12	0.29	0.004	0.027	0.002	-0.001	-0.001	-0.002	0.003	0.0015
		2030		0.39	0.13	14	0.16	0.003	0.026	-0.002	-0.001	0.002	-0.002	0.002	0.0005
		2330		0.30	0.12	16	0.10	0.003	0.033	-0.002	-0.001	-0.001	-0.002	0.002	0.0007
02/05/91		0230		0.28	0.12	15	0.09	0.002	0.009	-0.002	-0.001	0.002	-0.002	0.002	0.0009
		0530		0.23	0.12	16	0.07	0.004	0.006	-0.002	-0.001	-0.001	-0.002	0.002	0.0005
		0830		0.17	0.11	18	0.04	0.002	0.005	-0.002	-0.001	-0.001	-0.002	-0.001	-0.0002
		1130		0.14	0.09	21	0.08	-0.002	0.029	-0.002	-0.001	0.003	-0.002	0.001	0.0006
			Max	0.56	0.13	21	0.29	0.004	0.033	0.002	0.001	0.007	0.002	0.003	0.0018
			Min	0.14	0.09	12	0.04	-0.002	0.005	-0.002	-0.001	-0.001	-0.002	-0.001	-0.0002
			Mean	0.31	0.12	16	0.13	0.003	0.018	0.002	0.001	0.002	0.002	0.002	0.0008

Date	Weather	Time	Ppn	Fe	Mn	Ca	Al	Cu	Zn	Pb	Cr	Cd	Ni	As	Hg
02/07/91		0100	0.02												
		0200	T												
		0300	0.04												
		0400	0.03												
		0500	0.03												
		0600	0.02												
		0700	0.02												
		0800	0.04												
		0900	0.02												
		1000	0.03												
		1100	0.05												
		1200	0.07												
		1300	0.09												
		1400	0.07	2.1	0.32	12	1.40	0.007	0.061	0.019	0.002	0.003	0.003	0.005	-0.0002
		1600	0.10	2.7	0.30	7.7	1.60	0.007	0.055	0.016	0.002	-0.001	0.003	0.007	0.0043
		1800	0.03	1.1	0.16	11	0.60	0.006	0.029	0.007	-0.001	-0.001	-0.002	0.003	0.0013
		2000	0.04	0.77	0.14	10	0.42	0.005	0.021	0.002	-0.001	-0.001	-0.002	0.003	0.0006
		2200	0.01	0.61	0.15	13	0.30	0.004	0.019	-0.002	-0.001	0.001	-0.002	0.003	0.0011
		2400	T	0.48	0.11	15	0.24	0.005	0.019	-0.002	-0.001	-0.001	-0.002	0.002	-0.0002
02/08/91		0200	T	0.55	0.11	14	0.27	0.003	0.021	-0.002	-0.001	0.001	-0.002	0.002	
		0400		0.36	0.09	15	0.15	0.005	0.015	-0.002	-0.001	-0.001	-0.002	0.002	-0.0002
		0600		0.37	0.12	13	0.16	0.004	0.019	-0.002	-0.001	-0.001	-0.002	0.003	0.0007
		0800		0.29	0.09	14	0.08	0.004	0.011	-0.002	-0.001	-0.001	-0.002	0.002	0.0094
		1000		0.22	0.08	16	0.06	0.004	0.015	-0.002	-0.001	0.002	-0.002	0.002	0.0005
		1200		0.18	0.06	15	0.09	0.006	0.044	-0.002	-0.001	-0.001	-0.002	0.002	0.0011

Total ppt for st 0.72

				Fe	Mn	Ca	Al	Cu	Zn	Pb	Cr	Cd	Ni	As	Hg
			Max	2.70	0.32	16	1.60	0.007	0.061	0.019	0.002	0.003	0.003	0.007	0.0094
			Min	0.18	0.06	7.7	0.06	0.003	0.011	-0.002	-0.001	-0.001	-0.002	0.002	-0.0002
			Mean	0.81	0.14	13	0.45	0.005	0.027	0.005	0.001	0.001	0.002	0.003	0.0016

Date	Weather	Time	Ppn	Fe	Mn	Ca	Al	Cu	Zn	Pb	Cr	Cd	Ni	As	Hg
03/14/91	Dry	24-hr comp		0.15	0.09	12	0.13	0.04	0.02	-0.002	0.003	-0.001	-0.005	0.001	-0.0002
04/30/91	Wet	0530	0.01												
	2-hr	0730	0.04												
	comp	0930	0.13												
		1130	0.63	3.4	0.63	8.3	1.8	0.011	0.1	0.022	-0.002	-0.002	0.009	0.002	-0.0002
		1330	0.67	21.0	2.8	5.0	1.3	0.029	0.18	0.085	-0.002	-0.002	0.030	0.002	-0.0002
		1530	0.11	1.7	0.29	5.9	1.1	0.007	0.04	0.012	-0.002	-0.002	0.003	0.004	-0.0002
		1730	0.03	0.2	0.2	7.3	0.67	0.006	0.04	0.005	-0.002	-0.002	0.004	-0.001	-0.0002
		1930	0.05	0.86	0.15	8.3	0.44	0.005	0.02	0.003	-0.002	-0.002	0.002	0.001	-0.0002
		2130	T	0.65	0.13	9.2	0.35	0.003	0.02	-0.002	-0.002	-0.002	-0.002	0.002	-0.0002
		2330	T	0.51	0.1	9.4	0.22	0.002	0.03	-0.002	-0.002	-0.002	-0.002	-0.001	-0.0002
05/01/91		0130	T	7.5	0.66	4.8	4.9	0.013	0.07	0.029	-0.002	-0.002	-0.002	0.002	-0.0002
		0330	T	0.51	0.09	9.3	0.26	0.003	0.03	-0.002	-0.002	-0.002	-0.002	0.002	-0.0002
		0530	T	0.6	0.09	9.5	0.13	0.005	0.03	-0.002	0.011	-0.002	0.013	0.002	-0.0002
		0730	T	0.4	0.07	9.8	0.27	0.003	0.006	0.002	-0.002	-0.002	-0.002	0.002	-0.0002
		0930	T	0.46	0.08	9.8	0.18	0.003	0.02	-0.002	-0.002	-0.002	-0.002	0.003	-0.0002
		1130		0.29	0.06	12	0.21	0.003	0.03	-0.002	-0.002	-0.002	-0.002	0.002	-0.0002
		1330		0.29	0.06	12	0.19	0.002	0.02	-0.002	-0.002	-0.002	-0.002	0.002	-0.0002
		1530		0.27	0.05	12	0.07	0.002	0.011	-0.002	-0.002	-0.002	-0.002	0.002	-0.0002
		1730													
		1930		0.27	0.06	13	0.12	-0.002	0.02	-0.002	-0.002	-0.002	-0.002	0.001	-0.0002
		2130		0.05	-0.01	18	0.18	-0.002	-0.005	-0.002	-0.002	-0.002	-0.002	0.002	-0.0002
			Max	21.00	2.8	18	4.9	0.029	0.18	0.085	0.011	0.002	0.030	0.004	0.0002
			Min	0.05	-0.01	5	0.07	-0.002	-0.005	-0.002	-0.002	-0.002	-0.002	-0.001	-0.0002
			Mean	2.29	0.32	9.6	0.73	0.006	0.040	0.010	0.003	0.002	0.005	0.002	0.0002

Total rainfall for storm = 1.69

Date	Weather	Time	Ppn	Fe	Mn	Ca	Al	Cu	Zn	Pb	Cr	Cd	Ni	As	Hg
05/21/91	Dry	0600		0.11	-0.03	27	0.070	-0.03	0.014	-0.002	-0.002	-0.002	-0.002	-0.002	-0.0002
	6-hr	1200		0.10	-0.03	32	-0.050	-0.03	0.023	-0.002	-0.002	-0.002	-0.002	0.001	-0.0002
05/22/91	comp	0600		0.11	-0.03	30	-0.050	-0.03	0.030	-0.002	-0.002	-0.002	-0.002	0.001	-0.0002
		1200		0.10	-0.03	29	-0.050	-0.03	0.021	-0.002	-0.002	-0.002	-0.002	0.002	-0.0002
	24-hr ave			0.11	-0.03	30	-0.055	-0.03	0.022	-0.002	-0.002	-0.002	-0.002	-0.002	-0.0002
05/30/91	Wet	1600	T												
	2-hr	1800	0.13	0.07	-0.03	29	-0.05	-0.03	-0.005	-0.002	-0.002	-0.002	-0.002	0.002	-0.0002
	comp	2000	0.53	0.52	0.23	25	0.70	-0.03	0.060	0.012	0.002	-0.002	0.003	0.009	-0.0002
		2200	0.02	0.26	0.06	13	0.32	-0.03	0.030	0.010	-0.002	-0.002	0.002	0.006	-0.0002
		2400	0	0.2	0.06	13	0.13	-0.03	0.043	-0.002	-0.002	-0.002	-0.002	0.002	-0.0002
05/31/91		0200	0	0.2	0.03	17	0.07	-0.03	0.010	-0.002	-0.002	-0.002	-0.002	0.003	-0.0002
		0400	0	0.2	-0.03	23	0.06	-0.03	0.015	-0.002	-0.002	-0.002	-0.002	-0.001	-0.0002
		0600	0	0.17	-0.03	19	0.05	-0.03	0.010	-0.002	-0.002	-0.002	0.002	0.002	-0.0002
		0800	0	0.16	-0.03	26	0.05	-0.03	-0.005	-0.002	-0.002	-0.002	-0.002	0.003	-0.0002
	Total rainfall for storm = 0.68 in														
			Max	0.52	0.23	29	0.70	0.03	0.060	0.012	0.002	0.002	0.003	0.009	0.0002
			Min	0.07	-0.03	13	-0.05	-0.03	-0.005	-0.002	-0.002	-0.002	-0.002	-0.001	-0.0002
			Mean	0.22	0.06	21	0.18	0.03	0.022	0.004	0.002	0.002	0.002	0.004	0.0002

Date	Weather	Time	Ppn	Fe	Mn	Ca	Al	Cu	Zn	Pb	Cr	Cd	Ni	As	Hg
06/05/91	After 3 days of light rain			0.07	-0.03	18	-0.05	-0.03	0.02	-0.002	-0.002	-0.002	-0.002	0.002	0.0062
09/20/91	Wet	1100		0.64	2.2	16	0.05	0.025	-0.01	0.002	-0.001	-0.002	-0.002	0.004	-0.0002
		1200		0.06	0.14	15	0.17	0.26	0.02	0.015	-0.001	-0.002	-0.002	0.006	-0.0002
			Max	0.64	2.2	16	0.17	0.26	0.02	0.015	0.001	0.002	0.002	0.006	0.0002
			Min	0.06	0.14	15	0.05	0.025	-0.01	0.002	-0.001	-0.002	-0.002	0.004	-0.0002
			Mean	0.35	1.17	16	0.11	0.14	0.02	0.009	0.001	0.002	0.002	0.005	0.0002